A STUDY OF THE EFFECT OF SOURCE ON THE AGING CHARACTERISTICS OF ASPHALT BLENDS

A THESIS

Presented to

The Faculty of the Graduate Division

by

Herman Artis Hill

In Partial Fulfillment

of the Requirements of the Degree

Master of Science in Civil Engineering

Georgia Institute of Technology

June, 1966

A STUDY OF THE EFFECT OF SOURCE

ON THE AGING CHARACTERISTICS OF ASPHALT BLENDS

Approved:

Chairman

Date approved by Chairman 5/25/66

ACKNOWLEDGMENTS

The writer would like to express his appreciation to all those who offered assistance to him in the completion of this thesis. Special credit is extended to his thesis advisor, Dr. Paul Wright, for his counsel from the initial period of research design and formulation to the analysis and composition phase of the study.

Also, appreciation is extended to Professors B. B. Mazanti and Radnor J. Paquette for their comments regarding the content and organization of the thesis. Their suggestions have aided in clarification and improved readability of the study.

Recognition is also due the State Highway Department of Georgia, Materials Laboratory, Asphalt Section, for their advice and consideration during this research.

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SUMMARY

The research for this thesis was undertaken to investigate the effect of source on the aging characteristics of asphalt blends. The problem of variation in hardening properties of asphalt from different sources was observed by personnel of the Georgia State Highway Department, who suggested this study.

To determine this effect, asphalt samples of penetration grades 60-70, 85-100, and 120-150 were obtained from seven suppliers to the Highway Department. These grades of asphalt penetration were defined respectively as AC-6, AC-8, and AC-12. The AC-6 and AC-12 asphalt samples from the various sources were blended together to produce an AC-8 blend characteristic of both sources involved. This procedure provided for study of forty-two blend combinations.

An altered version of the Bureau of Public Roads Thin Film Oven Test was used to determine the aging characteristics of the blends. By correlating the results obtained using this aging test with data from other studies, it was indicated that this method offers a good procedure for predicting the asphalt behavior under service conditions. Each blend was aged for one, three, and five hours in an aging oven at 325° F. At the conclusion of the particular aging period, absolute viscosity tests were performed on the sample, using the sliding plate microviscometer.

From the viscosity data obtained, two series of graphs were drawn. One showed absolute viscosity as a function of aging time for the blends, and the second showed aging index as a function of aging time for the

blends. Both sets of graphs indicate that blending different grades of asphalt from different sources can be beneficial in some instances. However, care must be used in designing a blend and basic properties such as penetration, specific gravity, absolute viscosity, aging index and weight loss must be known. This blending can be accomplished without any apparent difficulty to create a homogeneous and workable mixture.

Considerable variation was encountered in the aging characteristics for some blends which could not entirely be explained due to lack of information. It appears that extensive data on individual blend components would be necessary to provide a satisfactory description of this variance problem.

The information obtained in this study indicates that selective blending of different asphalt grades and sources is practical and can be used to improve the aging characteristics of asphalts from a particular source.

CHAPTER I

INTRODUCTION

In this thesis the effect of blending asphalts from different sources upon asphalt hardening characteristics was studied. This problem of source is involved in the search for a proper test procedure to describe the "quality" of an asphalt. Quality of an asphalt refers to the ability of an asphalt to perform satisfactorily in all phases of its use from the mixing operation to the level of service it provides during its pavement life. This performance of an asphalt is influenced by the change in hardening during these periods.

Until 1956, all of the research dealing with artificial aging of asphalt used such tests as penetration, ductility, and softening point on the residue. These tests were in use as specification tests and therefore served as a useful measure of asphalt serviceability. From experience these tests have been shown to be excellent indicators of physical change in the asphalt.

Throughout the life of an asphalt mixture, from mixing to placing and usage, the asphalt is exposed in thin films. Initially these films are subjected to high temperatures which cause hardening even without action of light and in the presence of air. This hardening is due to the loss of volatiles from the asphalt, which causes a change in the chemical composition of the asphalt and consequently the potential serviceability of the pavement. The presence of oxygen during the heating allows oxidation to proceed along with volatilization, which will greatly increase the viscosity of the asphalt. From experience, an increase in viscosity has been found to be highly detrimental to the asphalt mix and is reason enough for practical concern to this complex problem.

Traxler[1*] in the discussion following his article mentions five causes of asphalt hardening. He lists them in an approximate order of importance as follows:

Oxidation

Volatilization

Time (development of internal structure on aging)

Polymerization induced by active light (free radical reactions)

Condensation polymerization (by heat)

The thin film oven test procedure was employed to age the various blends with other tests made to determine their aging characteristics. This method was first introduced by Lewis and Welborn[2] in 1940 and is now accepted as a standard for asphalt aging. They found that this test gave a good simulation of the mixing operation and some service exposure. According to Lewis and Welborn:

> The changes that occur during the thin film oven test for five hours with 1/8 inch films, in asphalts of the 50-60 grades are comparable to the changes that may be expected to occur in bitumen recovered from mixtures prepared in paving plants or from laboratory mixes prepared to duplicate paving plant practice.

Pauls and Welborn[3] also made some strong conclusions concerning the validity and practicality of the thin film oven test. A part of these conclusions follows:

> Of several test methods, the thin film oven test is the most suitable for use as a specification test because it requires the

*Superscript numbers refer to numbered references in Literature Cited at end of thesis.

> least amount of time, because the hardening of the asphalt is measured directly (rather than indirectly as in the case of the abrasion test and weathering strength test), and because the test does not require the extraction and recovery of the asphalt, as in the case of the Shattuck test and outdoor exposure tests, and thus eliminates any uncertainty regarding the effect of the recovery procedure on the characteristics of the weathered asphalt.

With this background of information indicating the usefulness of the thin film oven test results, the decision was made to use this type of accelerated aging test in this research.

Schweyer and Bransford[4] have published a very informative article describing the theoretical background and equipment used in making absolute viscosity tests. In this article they give the classical definition of viscosity as follows:

> When a plane one square centimeter in area requires a force of one dyne to move it at a velocity of one centimeter per second with respect to a second plane one centimeter distant, then the fluid between the planes has a viscosity of one poise equal one dyne-second per square centimeter.

They discuss the meaning of the above definition and arrive at a relation as shown below:

$$F = nS$$

where, F is the force in dynes per square cm.

S is the rate of shear in reciprocal seconds

n is the viscosity in poises

From this relation it is apparent that viscosity can be determined if the shear rate is measured while a sample between two plates is being subjected to a known force per unit area.

The procedure used in the Shell sliding plate microviscometer follows this concept. A known force is applied to the asphalt sample between two plates, and the amount of movement obtained per unit time is a measure of the shear rate. With this equipment the rate of movement can be measured by a micrometer dial and a stop watch, or by a graph recorder connected to the dial mechanism.

In 1956, Griffin, Miles, Penther, and Simpson[5] developed a method for measuring the absolute viscosity of an asphalt using the sliding plate microviscometer. Their introduction of this technique opened the way for a more sensitive and informative test than was previously possible. So far, the procedure has been used largely in research with very limited use as a specification control. This limitation in use is partly due to the lack of equipment and to a problem described by Fink.[6] He notes that large discrepancies may occur when using the microviscometer due to variation in film thickness and difficulty in applying the viscosity definition principle to the equipment design.

Viscosity data was obtained at the Georgia Institute of Technology using the principle and equipment mentioned above and was related to asphalt penetration with an empirical equation. This relationship developed by Wright and Paquette[7] is good for a wide range of values. This equation provides a needed bridge between the researcher's measurement, absolute viscosity, and the practician's measurement, penetration. This formula relates the absolute viscosity at 77° F to the standard penetration value and was developed from 152 data points using the least squares method. The relationship is:

$$\text{Absolute Viscosity, at } 77^\circ \text{ F} = \frac{3591.3}{(\text{Penetration})^{1.719}}$$

This formula provides a means of estimating the penetration after viscosity results are known. Penetration values, being more commonplace than absolute viscosity, serve as a useful and easily understood measure of asphalt hardening. Later in this report, the empirical relationship will be used to explain some of the results obtained with the microviscometer.

One of the important factors that can be associated with asphalt performance is the source of the asphalt crude. Many researchers have observed this from results of various tests indicating asphalt serviceability. However, many of these studies have directed their attention to the asphalt performance from one source only. In this study several sources were used in an effort to define this source effect.

This introduction has presented a concise summary of the research problem and some of the prior work in related asphalt projects. Many projects involving asphalt aging have been described in materials literature contributing greatly to the understanding of asphalt characteristics. Some of these not mentioned explicitly in the introduction have been listed as a supplemental bibliography.

CHAPTER II

PROCEDURE

The procedures used in this testing program followed the standard methods as closely as possible to ensure more meaningful and acceptable results. Where it was required to deviate from the standard test methods, a rational approach was used to provide a suitable alternate.

Source of Samples

It was decided to use the seven major asphalt suppliers of the State Highway Department of Georgia as sources for this research. This decision was made because the problem of variation in asphalt characteristics and performance due to source had been discussed with Department personnel. It was felt that some information could be obtained about this variation from a study concerning asphalt blends.

Also, at the same time, the Asphalt Laboratory personnel of the Highway Department were conducting tests on these same sources in an attempt to formulate standards involving absolute viscosity. Because of this dual interest in these sources, this writer was able to obtain samples with the help of experienced personnel. The following list shows the seven companies from which samples were obtained:

A. Shell Oil Company, Atlanta, Georgia

B. Humble Oil Company, Charleston, South Carolina

C. American Oil Company, Savannah, Georgia

D. Shell Oil Company, Savannah, Georgia

E. American Bitumen and Asphalt, Bainbridge, Georgia

F. American Bitumen and Asphalt, Savannah, Georgia

G. Cracker Asphalt Corporation, Douglasville, Georgia

Three samples were obtained from each of the above sources, one each of penetration grade 60-70, 85-100, and 120-150. Hereinafter, these penetration grades will be identified, respectively, as AC-6, AC-8, and AC-12.

The letters preceding the supplier's name indicates the identification used to denote the blend combination. For example, A6B12 means that the AC-6 from A source (Shell Oil Company, Atlanta) was blended with the AC-12 of the B source (Humble Oil Company, Charleston) to produce an AC-8 grade asphalt.

These sources were sampled at their respective locations by Highway Department inspectors. The one gallon sample was then shipped to the Atlanta laboratory, where it was heated and poured into quart cans. Two quart cans of each sample were used for this work.

Blending of Samples

Penetration tests were made on each of the three grades of asphalt from each source. This provided the information needed to predict what ratio of grades to use to obtain an AC-8 blend. By using the asphalt specific gravity to guide the selection of a ratio, it was usually not difficult to get the penetration within the desired range (85-100).

To obtain the desired AC-8 blend for testing, the various AC-6 and AC-12 samples were blended by weight in the correct ratio. Forty-two blends were prepared in this manner. A sample size of 180 grams was used which adequately permitted the preparation of three, 50 gram specimens for oven aging tests.

The AC-6 and AC-12 samples were heated in the oven to approximately 185° F before pouring into seamless tin cans for the mixture. After these two asphalts had been added together, the mixture was reheated to aid in blending the two grades. The blend was stirred slowly but completely to ensure a homogeneous combination of the asphalts. This blending procedure gave uniform blends as substantiated by the consistent penetration values obtained.

Penetration Tests

Penetration tests were made according to the standard ASTM Test Designation D5-61 using a temperature of 77° F, load of 100 grams, and time of five seconds. The three asphalt grades from each source and the forty-two blend combinations were tested as a control feature of the work. As mentioned above, the original, unaged penetration was used to select the proper weights of the components when they were blended. Since the samples were larger than the standard 50 gram size, they were cooled at 77° F for two hours before testing rather than the normal one hour.

Aging Tests

The blends were aged using the Bureau of Public Roads Standard Thin Film Oven Test, with some modifications. Although the B. P. R. method requires removal from the oven at five hours, for the purposes of this research, it was decided to age the blends for one, three, and five hours. This gave additional data concerning the rate of change for the various blend combinations.

Samples of approximately 1/8" film thickness in a flat bottom, five inch diameter pan were placed in a 325° F oven on a rotating shelf.

Three samples could be accommodated in the oven at one time. Two thermometers were used in the oven to provide precise temperature control.

The sample weight was very carefully controlled at 50 grams for all of the blends to ensure no variation due to different weights and thus different film thicknesses. Also, it was important to accurately know the sample weight for the weight loss determination. The loss was usually very small, so it was important to obtain a correct original weight to prevent a false weight change result.

The weight loss information was obtained for each of the samples at the completion of one hour, three hours, and five hours aging in the oven. At the end of a particular aging period, the sample was removed from the oven and immediately weighed. This was done to ensure that no additional loss of volatiles after removal would introduce error.

Viscosity Tests

Absolute viscosity tests using the sliding plate microviscometer were made on the unaged blend, and the one hour, three hours, and five hours samples aged in the oven. After the test results were complete, computations were made to determine the viscosity at a standard rate of shear.

The asphalt films for the unaged blends were prepared while the samples to be aged were being treated in the oven. The plates for the aged samples were made immediately after the samples were removed from the oven and the sample weights determined.

The plates used for the viscosity tests were made of glass and measured 2 cm. x 3 cm. These plates were heated in a 250° F oven for about five minutes preceding their use. This allowed the asphalt to be spread easily and more evenly on the plates.

In order to form a uniform film thickness, the plates were pressed together immediately after the asphalt was applied. This procedure was performed while viewing a light source through the asphalt film which ensured that the asphalt was uniformly spread over the plates. After some practice, it was not difficult to obtain a desired film thickness of 40-60 microns.

When a uniform film had been obtained between the plates, the sample was allowed to cool, after which excess asphalt was scraped from the sides of the plates. The outside of the plates was then cleaned lightly with benzene to ensure determination of the correct weight of the asphalt film. The weight of the sample was measured to the nearest ten thousandth gram by a precise balance. The film thickness in microns was calculated by dividing the weight of the asphalt by the product of the plate area and the asphalt specific gravity. A sample of these calculations is given in the appendix. The asphalt plates were allowed to cool and remain at room temperature for at least one hour before the viscosity tests were made.

Absolute viscosity tests were made using the sliding plate microviscometer developed by Shell Research Corporation. This machine measures the movement of one plate with the other fixed when it is subjected to a load. The plates were tested in a constant temperature water bath at 77° F, which approximates the normal air temperature to which asphalt is exposed in service. A Varian graphical recorder was used to record the amount of movement of the plates when subjected to various loads. With this instrument a visual indication was presented of the shear rate, which greatly simplified this phase of the computations.

Since asphalt viscosities may vary with shear rate, it is often necessary to report viscosities at a standard rate of shear. A shear rate of 0.05 seconds^{-1} was used in this research. To define this viscosity, viscosities were obtained at four shear rates surrounding 0.05 reciprocal seconds. Then these values were plotted on graph paper, a curve drawn through them, and the absolute viscosity at 0.05 seconds^{-1} determined from this data.

CHAPTER III

INSTRUMENTATION AND EQUIPMENT

Simple Balance

A triple beam, metric balance with 610 grams capacity made by the Ohaus Corporation was used in measuring the proportions for the asphalt blends.

General Use Oven

An upright oven with temperature range to 650° F, and thermostatically equipped to provide precise temperature control, was used as a general purpose oven for various phases of the work.

Asphalt Aging Oven

This oven is manufactured by Precision Scientific Company with a temperature range to 350° F, and fitted with a 10" rotating shelf. It was used to age the asphalt blends for periods of one, three, and five hours.

Glass Plates

These plates were 2 cm. x 3 cm., made of polished borosilicate plate glass and manufactured by Hallikainen Instruments Company. These plates were used to determine the absolute viscosity as described in other parts of this report.

Mettler Precise Balance

This sensitive balance was used to determine the asphalt film thickness and was capable of a direct reading to the nearest ten thousandth gram. It was manufactured by the Mettler Corporation.

Sliding Plate Microviscometer

The sliding plate microviscometer was used to calculate absolute viscosity at 77° F as discussed in this study. This equipment is manufactured by Hallikainen Instruments Company.

Model G-10 Millivolt Recorder

This recorder was used to follow the movement of the glass plates in the microviscometer and provided a more desirable means of determining the shear rate than using the microviscometer alone. It is manufactured by Varian Associates.

CHAPTER IV

DISCUSSION OF RESULTS

Relation of Aging Time and Viscosity

The effect of the oven aging time on asphalt viscosity is shown in the following graphs. By Figures 3-9 there is given a graph for each of the seven blends, using the AC-6 sample of each source. By Figures 10-16 is shown a set of seven graphs for each of the AC-12 samples from the sources. Also shown on the graphs is a plot of the respective AC-8 sample viscosity results. Data used for these graphs is shown in Tables 7-15 in the Appendix.

In Figures 3 and 4 for the AC-6 combinations, the Shell Oil, Atlanta, and the American Bitumen and Asphalt, Savannah, show similar results. Both of these sources had their respective blends about evenly dispersed about their AC-8 results. This would indicate that blending these sources with the other sources studied had little overall effect.

However, the graphs for Humble Oil, Charleston; American Oil, Savannah; and Cracker Asphalt, Douglasville, Figures 5, 6, and 7, showed the interesting trend of the blends having smaller viscosity values than the respective AC-8 values. In other words, for resistance to aging, judged by the thin-film oven test, the AC-6's of these sources produce better AC-8 asphalts when blended with AC-12's of the other sources studied. The results indicate that these asphalts which have a relatively high susceptibility to hardening can be improved by blending with an asphalt of lower hardening susceptibility.

Two other sources, Shell Oil, Savannah, and American Bitumen and Asphalt, Bainbridge, Figures 8 and 9, show different results concerning their AC-6 blends. In this case, when their respective AC-6 samples were mixed with AC-12's from the other sources the AC-8 combination in general gave a higher viscosity value than the AC-8 of these sources. This result could substantiate the present blending operation of these sources and verifies that they are obtaining a good comparative resistance to aging in their asphalts. Also, it shows these asphalts are relatively resistant to hardening, and blending with other asphalts tends to increase their hardening susceptibility.

The second set of graphs, Figures 10-16, shows the results of the AC-12 samples blended with AC-6's from the other sources. Three of the sources showed an overall viscosity range for the blends about equivalent to the AC-8 of the respective sources. These were A. B. A., Bainbridge; A. B. A., Savannah; and Cracker Asphalt, Douglasville, Figures 10, 11, and 12. These graphs would probably indicate that any blending to improve the asphalt quality would have to be selective, since the blends gave higher or lower viscosity values.

Three sources--Shell Oil, Atlanta; American Oil, Savannah; and Humble Oil, Charleston--had lower viscosity values with the blends than the regular AC-8. See Figures 13, 14, and 15. The first two sources, when blended with the AC-6 from Humble Oil, gave higher viscosity values than the regular AC-8. However, the AC-8 from Humble Oil had higher values than any of its blends. These graphs suggest that these three suppliers may produce a better quality asphalt by blending their AC-12 with an AC-6 from another source.

On the other hand, only one source--Shell Oil, Savannah--showed higher viscosity values than the AC-8 sample (Figure 16). With only one exception, all blends had higher viscosity readings than the AC-8 sample. When combined with the Humble Oil AC-6 sample, the blend had a lower viscosity than the AC-8 from Shell Oil, Savannah. From this graph, it seems that in general the AC-8 from this source could not be improved by blending techniques.

Relation of Aging Time and Aging Index

The next general area of data obtained concerned the aging index of the blends. Aging index (sometimes referred to as relative viscosity) is found by dividing the original viscosity into the final viscosity. This may be considered a much better indication of the aging characteristics of the asphalt, since a ratio of viscosities is used rather than the final viscosity itself. This topic also has two series of graphs similar to the previous discussion.

The first set of graphs, Figures 17-23, show the results obtained by combining the AC-6 samples from the various sources with AC-12 from other sources. The first four graphs, Figures 17-20, have a common trend and are discussed first. Each of these have their results grouped around the respective AC-8 curve. However, Shell Oil, Atlanta, and Shell Oil, Savannah, are more similar because each of them has values for blends generally higher than the AC-8 sample. This would indicate that these sources could not be improved by blending with any of the other sources studied.

Another source, A. B. A., Bainbridge (Figure 19), is rather evenly dispersed about the AC-8 value, indicating a selective blending process could produce an asphalt with better characteristics than their present one. Still another source--A. B. A., Savannah--had most of its blends with aging index values below the AC-8 results (See Figure 20). This trend would suggest that perhaps the present blending method could definitely be improved by using different AC-12 sources.

The other three sources of this set showed a somewhat different trend than the others. The blends from all of these sources showed much lower aging index values than did the respective AC-8 asphalts. These sources were Humble Oil, Charleston; American Oil, Savannah; and Cracker Asphalt, Douglasville. See Figures 20-23. These graphs indicate to a greater degree the improvements that may be expected by using different AC-12 samples than are presently being used.

The next set of graphs, Figures 24-30, shows the results of the AC-12 combinations of the various sources studied. In these combinations, Shell Oil, Atlanta, and Shell Oil, Savannah, showed no trend in either direction. That is, half the blends had higher values and half had lower values than the respective AC-8 samples as shown in the first two graphs, Figures 24 and 25.

Results for A. B. A., Bainbridge, and A. B. A., Savannah, indicate that most of the blends had higher values than the AC-8 sample (Figures 26 and 27). American Oil, Savannah, and Cracker Asphalt, Douglasville, showed opposite trends from the above sources (Figures 28 and 29). Most of the blends for these asphalts had values less than the AC-8 samples. The general result from these four graphs indicates that to improve asphalt characteristics, selective blending is necessary.

The results for Humble Oil, Charleston, Figure 30, showed the most spectacular difference. The regular AC-8 value was much higher than any of those for the blends. Specifically, the AC-8 had almost twice the aging index as the highest blend value. The results indicate that the aging characteristics of this asphalt could be substantially improved by blending with any of the other asphalts tested.

Original Penetrations

It was initially attempted to establish the required final penetration readings within a narrow range about 92. However, unexpected difficulties were encountered in accurately predicting this final penetration, so this requirement was relaxed. All of the resulting penetration values were within the 85-100 range. The following tables show the original penetrations obtained for the blends (See Tables 1-3). This test was used as a quality control on the blending to ensure uniform asphalts. In the tests made, almost half the blends were in the 90-95 range, which indicates the precision of the work performed.

Comment on Blending

Even though the asphalt used in the testing program came from seven different sources, no difficulty was experienced in blending them together. It had been thought that due to the differences in source and manufacturing technique some asphalts would not blend together well. This would have been detected by a variance in the penetration readings for each sample. However, the results of the penetration tests did not vary widely and were accepted as an indication of good homogeneous blends.

Sensitivity to Hardening

The phrase "sensitivity to hardening" is defined as the variation

Table 1. Penetration Results for the Original Source Samples

Source	AC-6	AC-8	AC-12
A	72	84	143
B	67	90	138
C	61	93	127.
D	60	88	134
E	64	86	125
F	62	87	124
G	67	91	143

Table 2. Penetration Results for the X6 Blend Samples

Blend	Penetration	Blend	Penetration
A6B12	86	F6A12	87
A6C12	85	F6B12	87
A6D12	87	F6C12	88
A6E12	90	F6D12	85
A6F12	92	F6E12	92
A6G12	96	F6G12	88
B6A12	92	G6A12	93
B6C12	98	G6B12	97
B6D12	95	G6C12	90
B6E12	94	G6D12	93
B6F12	97	G6E12	98
B6G12	94	G6F12	95
C6A12	89		
C6B12	89		
C6D12	88		
C6E12	93		
C6F12	89		
C6G12	95		
D6A12	89		
D6B12	86		
D6C12	89		
D6E12	85		
D6F12	88		
D6G12	85		
E6A12	87		
E6B12	93		
E6C12	95		
E6D12	91		
E6F12	92		
E6G12	95		

Table 3. Penetration Results for the X12 Blend Samples

Blend	Penetration	Blend	Penetration
A12B6	92	F12A6	93
A12C6	89	F12B6	97
A12D6	89	F12C6	89
A12E6	87	F12D6	88
A12F6	87	F12E6	92
A12G6	93	F12G6	95
B12A6	86	G12A6	96
B12C6	89	G12B6	94
B12D6	86	G12C6	95
B12E6	93	G12D6	85
B12F6	87	G12E6	95
B12G6	97	G12F6	88
C12A6	85		
C12B6	98		
C12D6	89		
C12E6	95		
C12F6	88		
C12G6	90		
D12A6	87		
D12B6	95		
D12C6	88		
D12E6	91		
D12F6	85		
D12G6	93		
E12A6	90		
E12B6	94		
E12C6	93		
E12D6	85		
E12F6	92		
E12G6	98		

in hardening an asphalt displays when blended with asphalts from other sources. This was indicated by the viscosity and aging index results shown in Tables 7-15. However, a clear pattern was not shown as was expected. For example, the AC-8 sample from Humble Oil, Charleston, showed a very high viscosity and aging index. Yet, when blended with the other sources, the blends did not show similar high values. On the other hand, Shell Oil, Atlanta, and A. B. A., Bainbridge, had low viscosity and aging index values. But, when combined with other sources, Shell Oil gave higher values and the A. B. A. blends were about the same or lower than the AC-8.

In order to fully explain the reason for this difference in the resulting blend from the AC-8 originals, a detailed investigation into the aging characteristics of the AC-6 and AC-12 components from the sources would be necessary. However, in this research, this type information was not obtained. Lacking this data, a study of the penetration values for the components and resulting blends was made to determine if any relationship existed that would describe the asphalt hardening characteristics. From the available penetration data a definite pattern was not found that would indicate any influence on the blends by the variable component. The aging characteristics of the blends varied considerably, and no clear trend was established to correlate the penetration values with them.

Sample Size Test

During the first phase of the testing program, it was decided to consider various sample sizes and study the aging differences. The standard 50 gram size was used first; then another was prepared weighing 25 grams and still another weighing 12.5 grams. The A. B. A., Bainbridge, sample was selected for this study, since it was the only AC-8 sample that had no weight loss for the standard oven test.

The samples of the other weights were aged for 5 hours, at 325° F and then tested for weight loss and absolute viscosity change. As shown in the accompanying Table 4 and Figure 1, the change in viscosity and weight loss followed an exponential pattern. For the 12.5 gram size, the oven aging appeared to be quite severe. The asphalt had become very hard and difficult to form after the oven exposure. Wright's[7] formula shows that this viscosity is equivalent to a penetration of 21. This penetration gives an indication of the amount of hardening experienced by the asphalt since the original penetration was 86. Coon's[8] research indicates that this viscosity is equivalent to that of an asphalt after about 10 years of service life.

After this data had been obtained and other factors considered, it was dediced to use the 50 gram size sample for the work. This would provide a standard test method with which comparisons with other research could be made. Also, as mentioned previously, the smaller sample sizes gave more severe hardening and created more problems in making viscosity plates and measuring the viscosity with the microviscometer.

Weight Loss Tests

The findings made under this phase of the research appear to be consistent with data from other studies. Weight losses for the samples ranged from 0 to 0.7 grams. A histogram of these losses is shown which graphically portrays these results in a more easily understood form (See Figure 2).

It can be seen that only four samples had a loss of more than 0.3 gram with 37 showing 0.3 gram or less. The weighted mean for all the data is

Table 4. Sample Size Test Results

Sample Size (Grams)	Five Hours Viscosity (Megapoises)	Weight Loss (Grams)	Per Cent Weight Loss
50	3.88 4.02 Avg. = 3.95	0	0
25	9.80 7.87 Avg. = 8.84	- 0.1	- 0.2
12.5	17.6	- 0.2	- 0.4

Note: Sample used was the AC-8 Original from A. B. A., Bainbridge.

Original Viscosity (Megapoises)
0.948 0.936 Avg. = 0.942

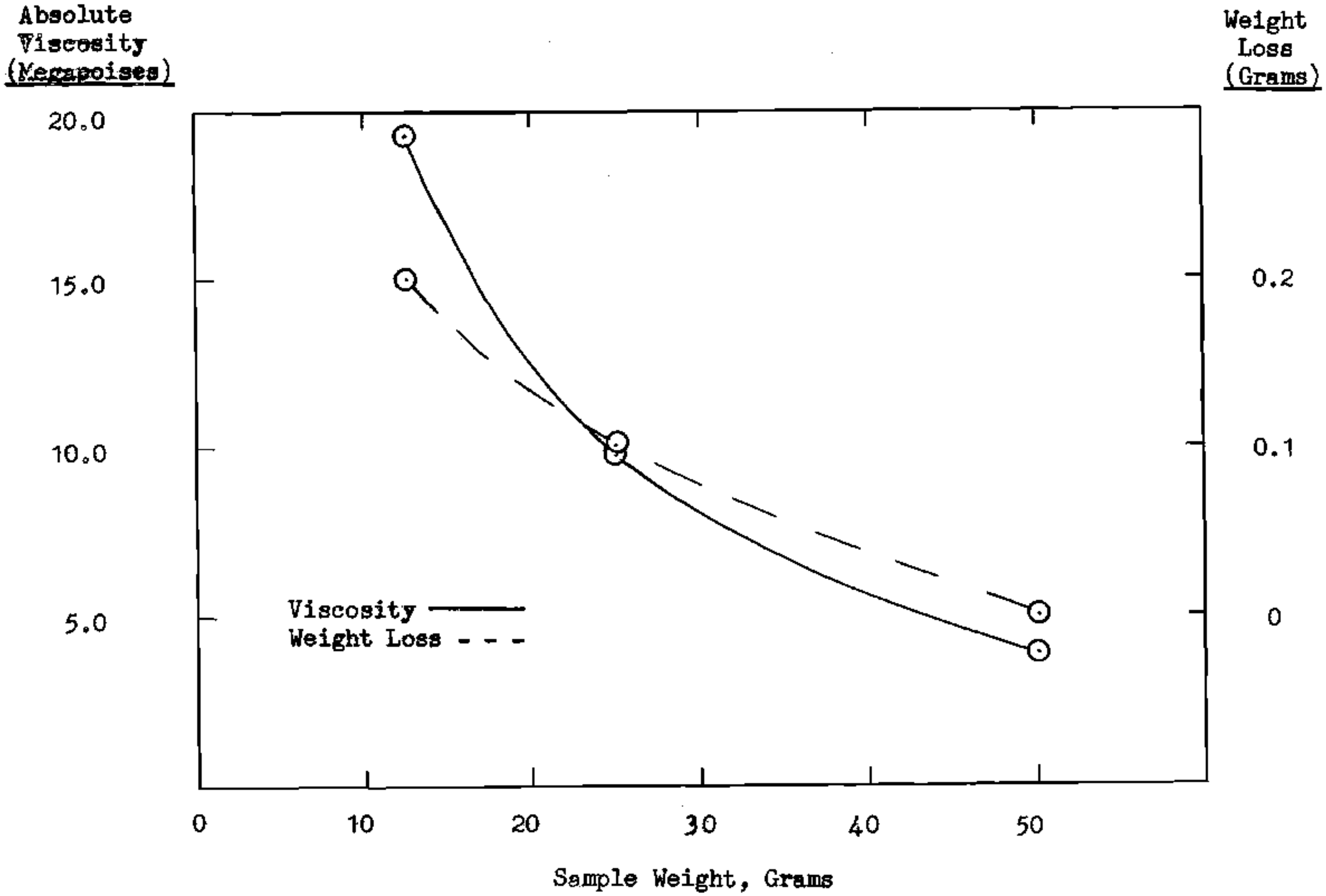

Figure 1. Relation of Sample Weight to Absolute Viscosity and Weight Loss.

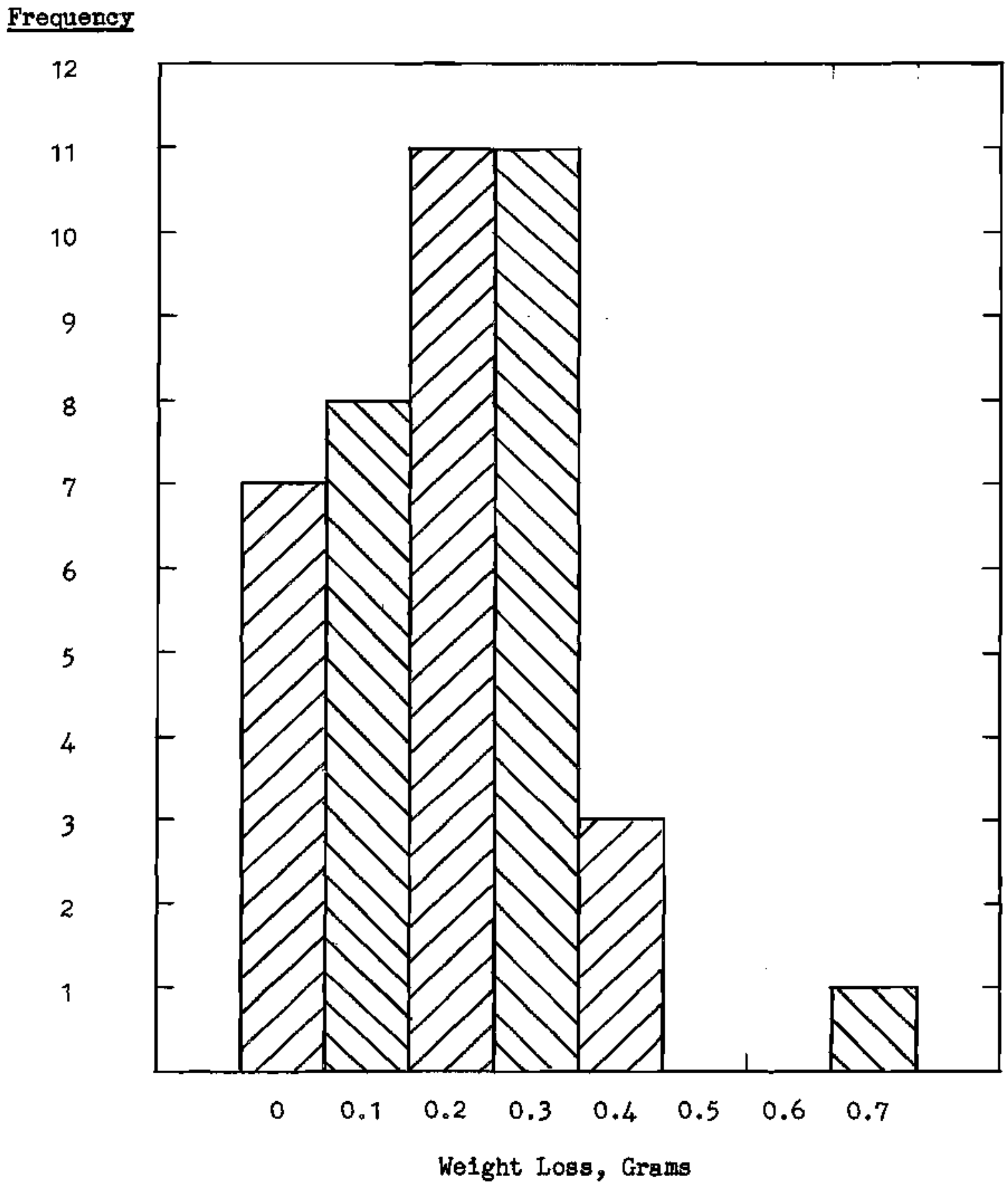

Figure 2. Weight Loss Histogram.

0.2 gram and indicates a good performance of these samples. Seven of the samples, or 17 per cent, showed no loss after five hours' aging at 325° F. Complete data on all samples for weight loss is shown in Tables 16-18 in the Appendix.

Table 5 shows a comparison of the AC-8 weight losses of the various producers, with an average of the AC-6 and AC-12 weight losses. For example, the American Oil, Savannah, asphalt shows a weight loss of 0.3 gram for the AC-8 sample. Then the average weight loss of all blends made from AC-12 of this source is listed as 0.2 gram, and the average of the blends using AC-6 of this source is 0.23 gram.

The table shows some interesting trends concerning the blends and the sources. The four AC-8 samples that had a weight loss after oven aging were higher than the AC-6 blend average weight loss. In other words, the AC-6 blend average for these sources indicated less susceptibility to aging than the AC-8 samples. In comparing the AC-12 blend average with the AC-8 loss, it is seen that three of four had weight losses less than the AC-8 reading. Again this indicates a trend that on the average the blends have more resistance to aging than the AC-8 samples.

The trends noted above are not as pronounced as may be indicated, since the data are only averages. However, a check of the actual weight losses of each sample reveals that there are several in each blend group with losses less than the AC-8 sample. With this overall representation the trends appear to be established.

Theoretical Penetration Change

As noted earlier in this report, Wright and Paquette[7] have done work in asphalt hardening. During their study, an empirical formula was

Table 5. Comparison of Average Weight Loss Results of Blends and AC-8 Original Samples

Source	Original AC-8 Weight Loss	Average Weight Loss of Blends Using AC-12 from Source	Average Weight Loss of Blends Using AC-6 from Source
A	+ 0.20	- 0.15	- 0.23
B	+ 0.30	- 0.17	- 0.23
C	- 0.30	- 0.20	- 0.23
D	- 0.10	- 0.18	- 0.07
E	0	- 0.18	- 0.03
F	- 0.50	- 0.30	- 0.18
G	- 0.60	- 0.15	- 0.35

All Weight Loss Values in Grams

developed that related absolute viscosity and penetration values. This relationship was developed from a large amount of data and is considered to be reasonably reliable in describing the change in asphalt as hardening occurs. Using this relationship, the penetration value corresponding to the known five-hour viscosity was calculated. Tables 19-24 in the Appendix show this information for all samples tested in this study.

The table showing results for the averages, Table 6, indicates that the amount of hardening did vary according to the sources used in the blend. It can be seen that the "B" sample, Humble Oil Company, Charleston, did vary considerably according to how it was blended. When its AC-6 was blended with the AC-12's of other suppliers, there was an average penetration change of 49. When its AC-12 was added to the AC-6's of the others, the average result was a 39 point penetration change. Its own AC-8 sample showed a 56 point penetration change to lead the blends.

On the other end of the spectrum, Cracker Asphalt showed little difference in the amount of penetration change due to the various blend combinations. It varied from an average change of 44 when blended with AC-12's to a 46 point change when mixed with AC-6's. The other samples showed varying amounts of change, with a predominant value in the low forties.

The average final penetration value calculated from the formula was 46 for all the samples. This value gives an indication of the degree of hardening experienced by these blends. In comparison with work of other researchers, Coons[8] had a calculated final penetration of 32 for the AC-8 sample taken from pavement four years old. These figures show the amount of hardening that occurred in the samples and indicate the relation of laboratory aging to actual pavement life.

Table 6. Theoretical Penetration Change for Blend Averages

Blend Average	Average Unaged Viscosity	Average Five Hour Viscosity	Average Original Penetration	Average Final Penetration (From Formula)	Penetration Change
A6X12	1.05	4.91	89	46	43
B6X12	0.786	4.96	95	46	49
C6X12	1.17	4.67	90	48	42
D6X12	1.16	4.77	87	47	40
E6X12	1.04	4.49	92	49	43
F6X12	1.15	4.84	88	47	41
G6X12	0.945	4.34	94	50	44
A12X6	1.05	4.69	89	48	41
B12X6	1.03	4.36	89	50	39
C12X6	1.06	5.08	91	46	45
D12X6	1.09	4.73	90	47	43
E12X6	0.968	4.16	92	51	41
F12X6	0.972	4.95	92	46	46
G12X6	0.984	5.02	92	46	46
A8	1.17	4.84	84	47	37
B8	0.918	8.51	90	34	56
C8	0.944	5.81	93	42	51
D8	0.976	4.30	88	50	38
E8	0.942	3.95	86	52	34
F8	1.09	4.97	87	46	41
G8	0.906	5.01	91	46	45

Viscosity Values in Megapoises

CHAPTER V

CONCLUSIONS

From results of this research the following conclusions have been made concerning the asphalt blends and sources studied:

1. The effect of blending different sources of AC-6 and AC-12 asphalts varies depending on the source combination, and a blend resulting in beneficial characteristics must be designed using such basic properties as penetration, specific gravity, absolute viscosity, aging index and weight loss.

2. Asphalts of different sources and penetration grades can be blended together well to create a homogeneous and workable mixture.

3. The results obtained from the asphalt aging test used in this research indicates that it is a good laboratory method for predicting the asphalt behavior under service conditions.

4. An asphalt with low hardening resistance from one source can be blended with an asphalt of higher hardening resistance from another source to produce an AC-8 blend that has greater resistance to hardening than the original AC-8 blend of the first source provided the asphalt from the second source has a greater hardening resistance than the blend component it replaces from the first source.

CHAPTER VI

RECOMMENDATIONS

The experimental work described in this thesis has suggested other areas for study as outlined in the recommendations below:

1. A study to obtain penetration and absolute viscosity data for several different sources would allow formulas similar to Wright and Paquette's to be derived according to source.

2. An investigation to find better and more detailed information concerning the rate of hardening of asphalts would be beneficial.

3. Further study should be given a proposal to use asphalt combinations by making asphalt mixes and aging them. This would enable samples to be aged under conditions similar to actual service life and possibly provide greater insight into the practical results of this research.

4. A practical study should be made to determine the problems and solutions involved in combining different asphalt penetration grades from various sources for use under construction conditions.

APPENDIX

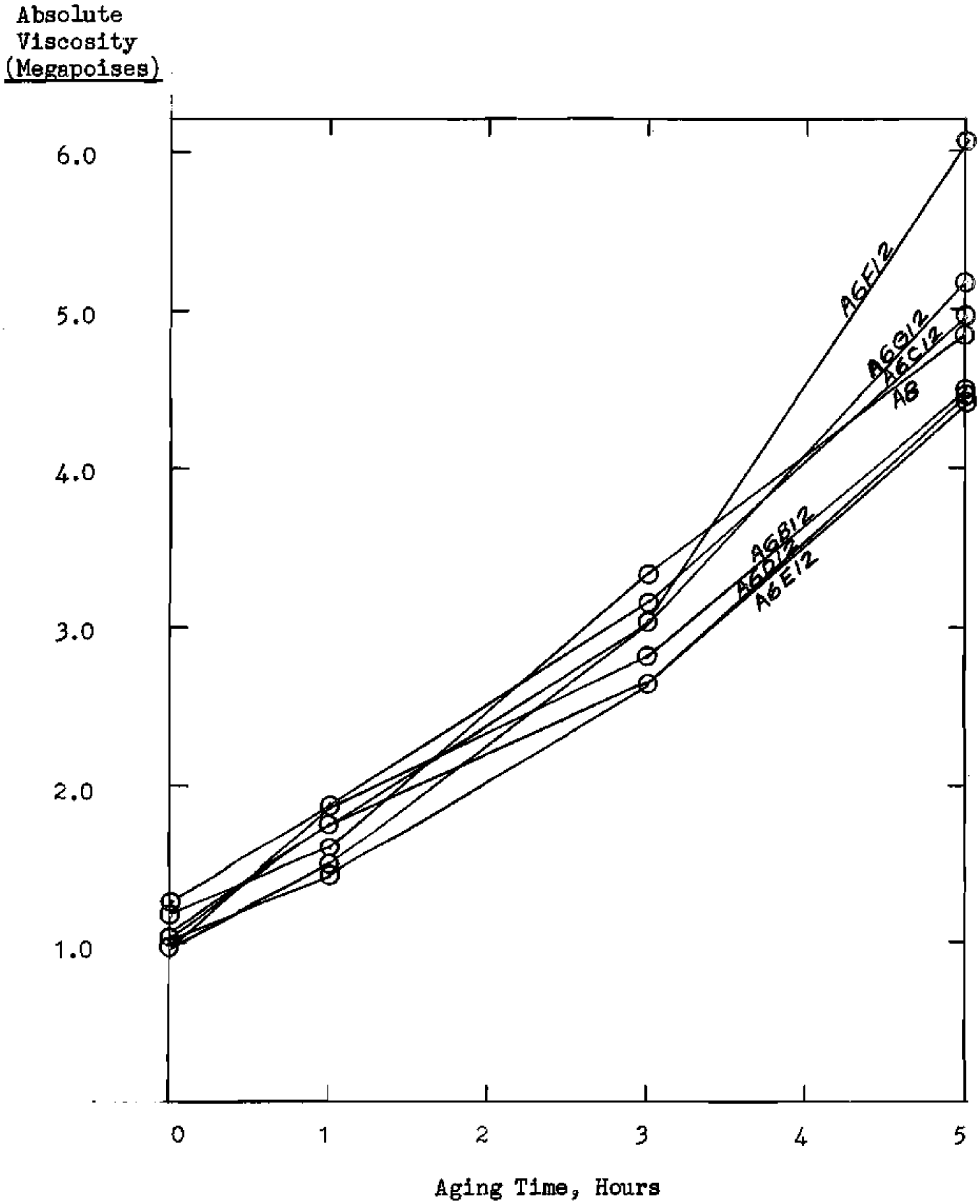

Figure 3. Relationship of Absolute Viscosity and Aging Time for the A6 Blends (Shell Oil Company, Atlanta).

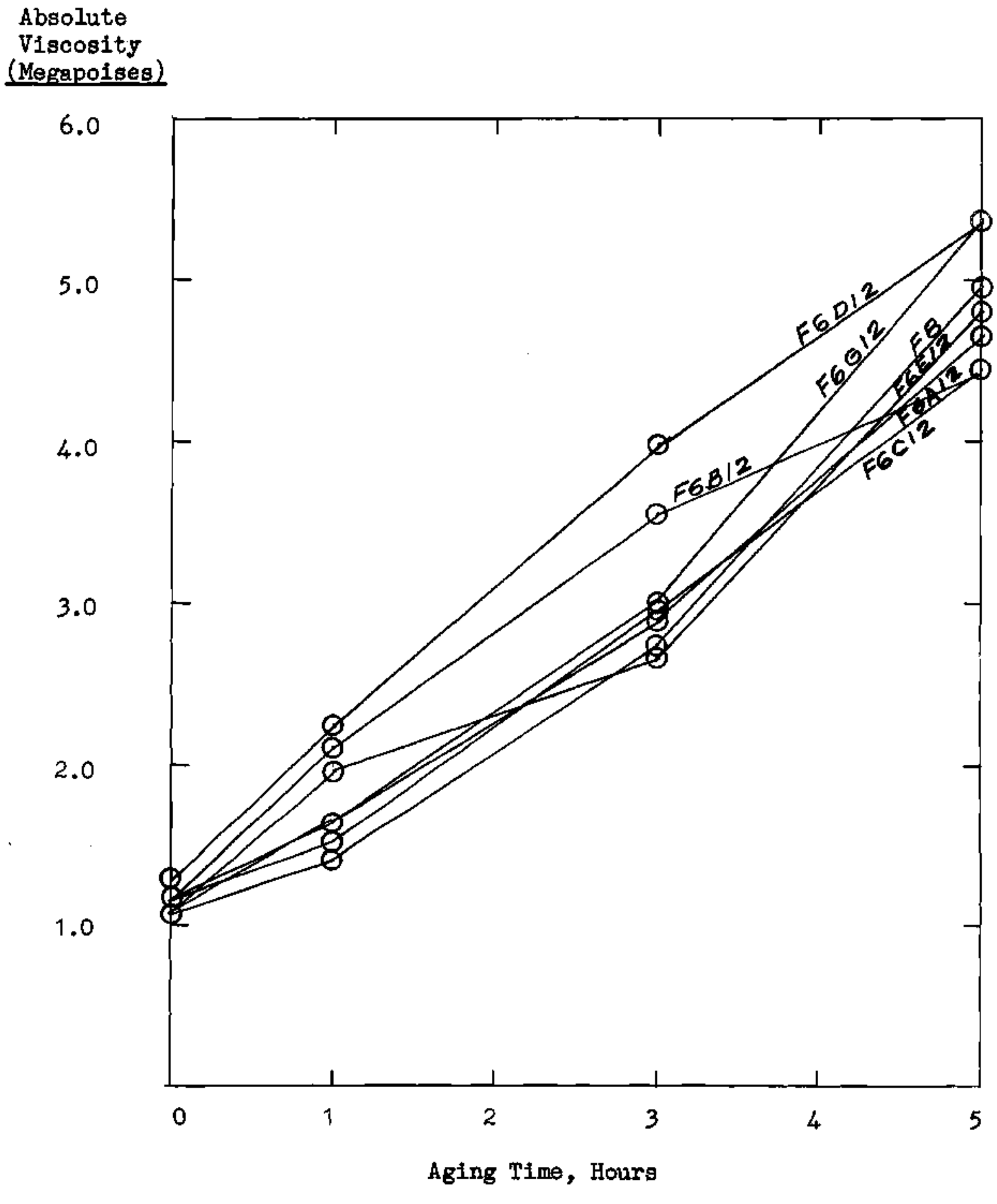

Figure 4. Relationship of Absolute Viscosity and Aging Time for the F6 Blends (American Bitumen and Asphalt, Savannah).

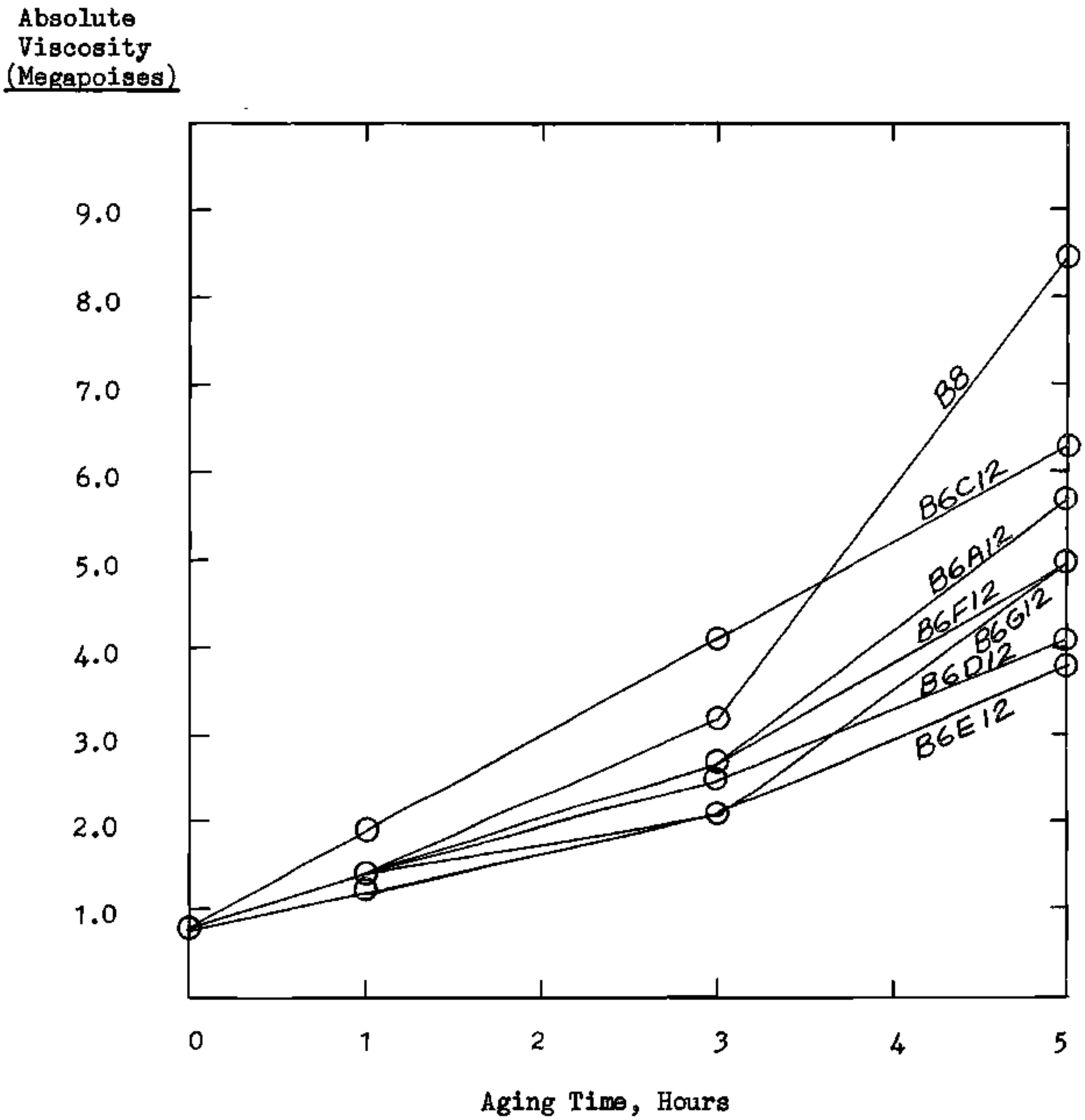

Figure 5. Relationship of Absolute Viscosity and Aging Time for the B6 Blends (Humble Oil Company, Charleston).

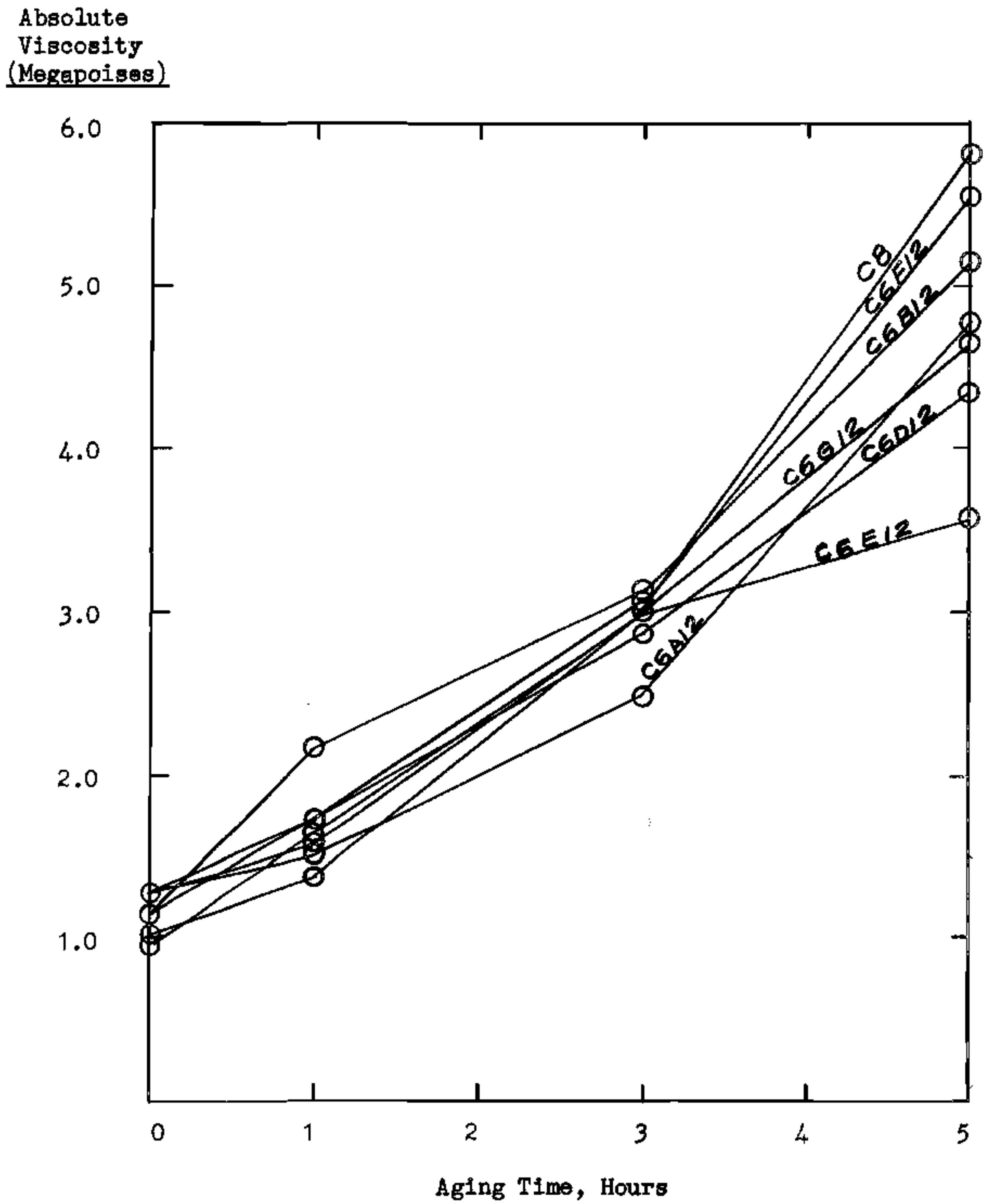

Figure 6. Relationship of Absolute Viscosity and Aging Time for the C6 Blends (American Oil Company, Savannah).

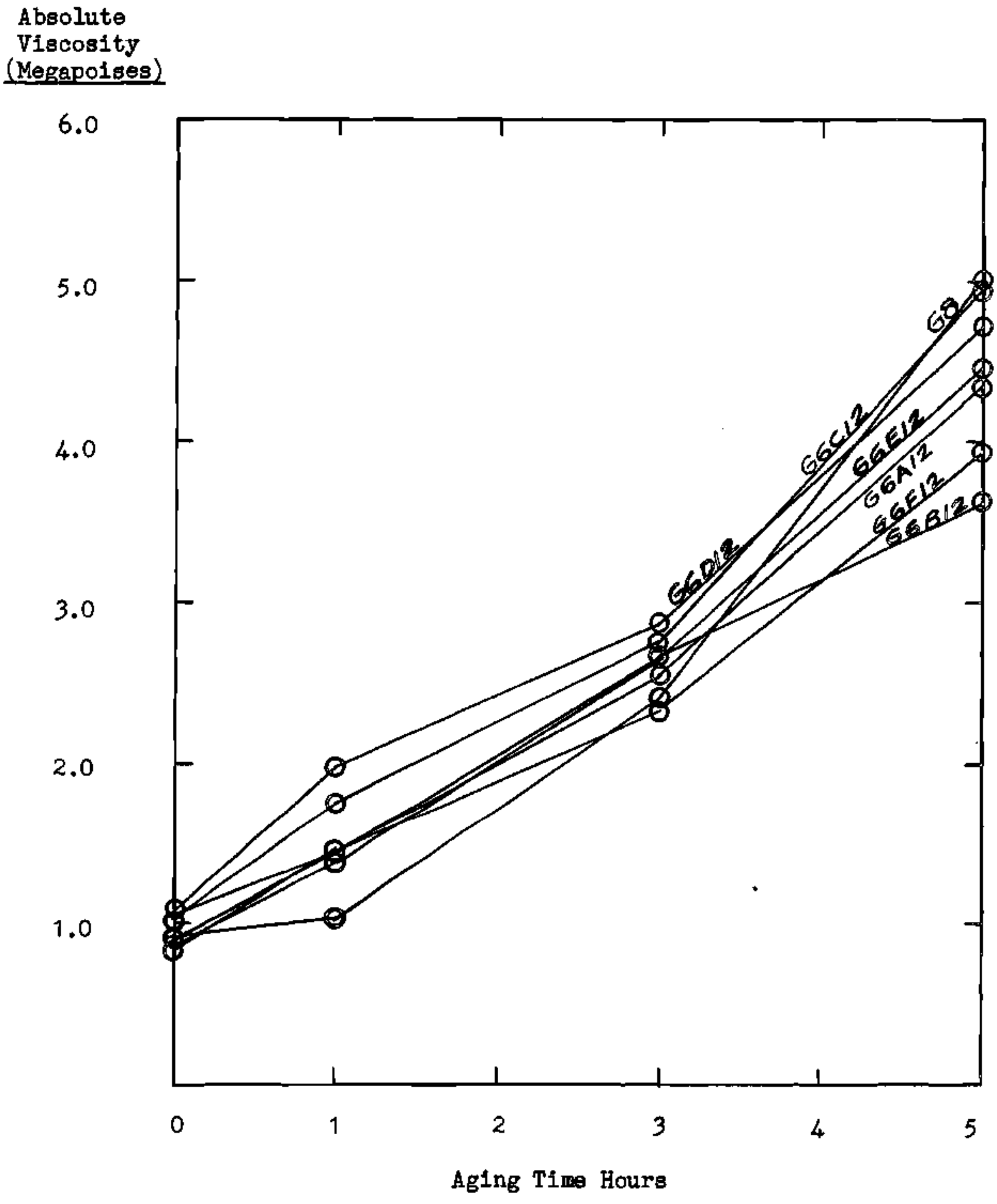

Figure 7. Relationship of Absolute Viscosity and Aging Time for the G6 Blends (Cracker Asphalt Corporation, Douglasville).

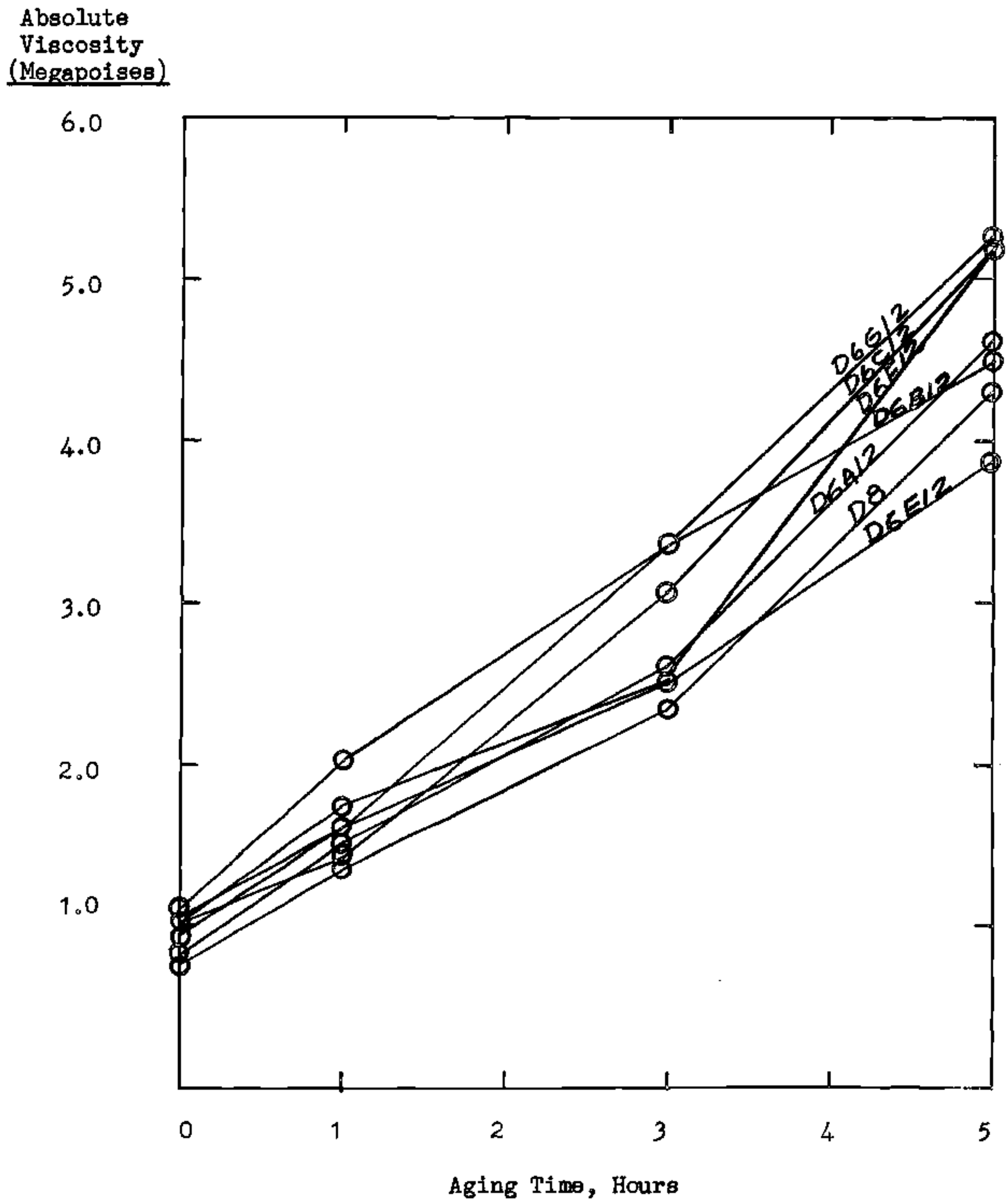

Figure 8. Relationship of Absolute Viscosity and Aging Time for the D6 Blends (Shell Oil Company, Savannah).

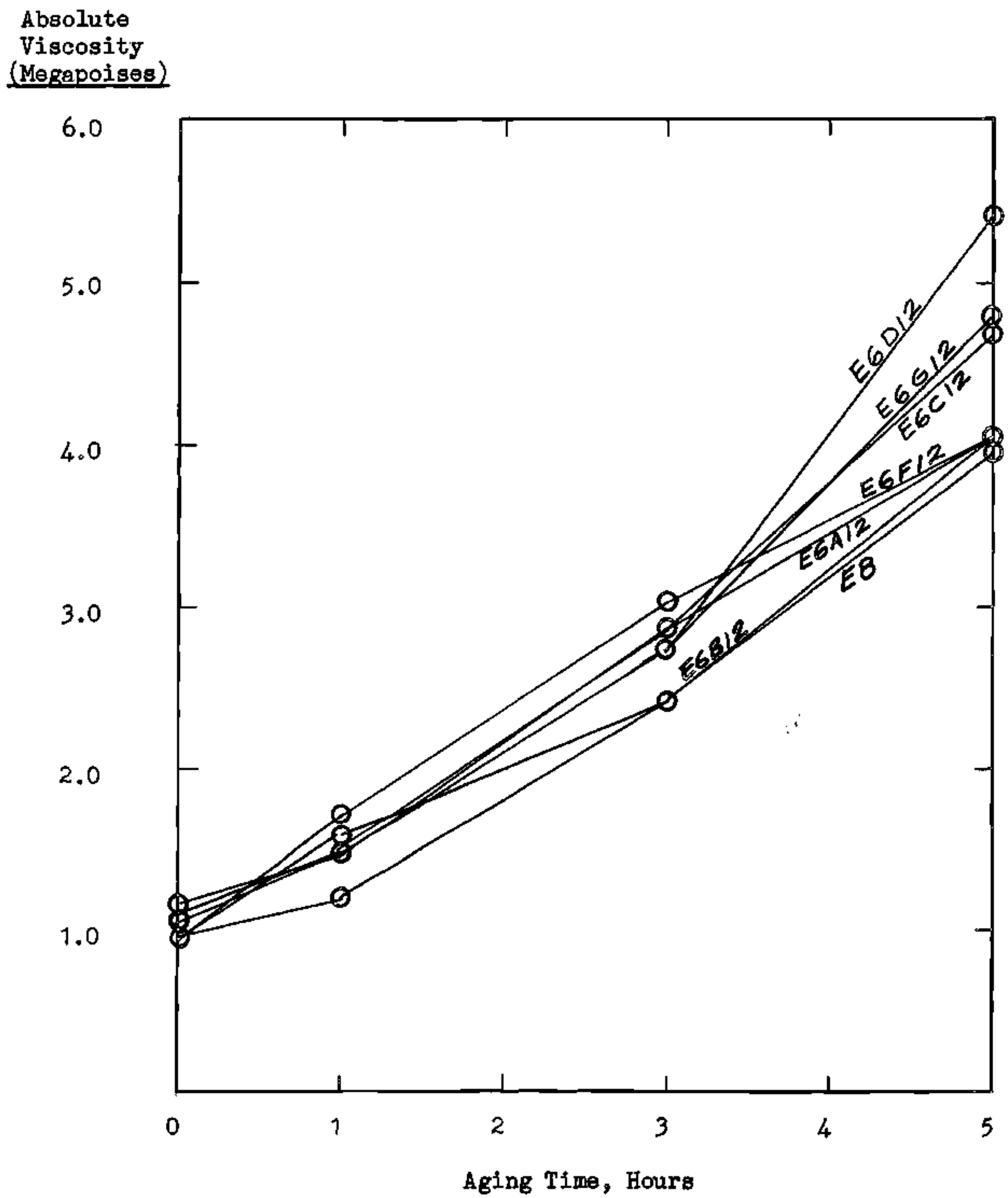

Figure 9. Relationship of Absolute Viscosity and Aging Time for the B6 Blends (American Bitumen and Asphalt, Bainbridge).

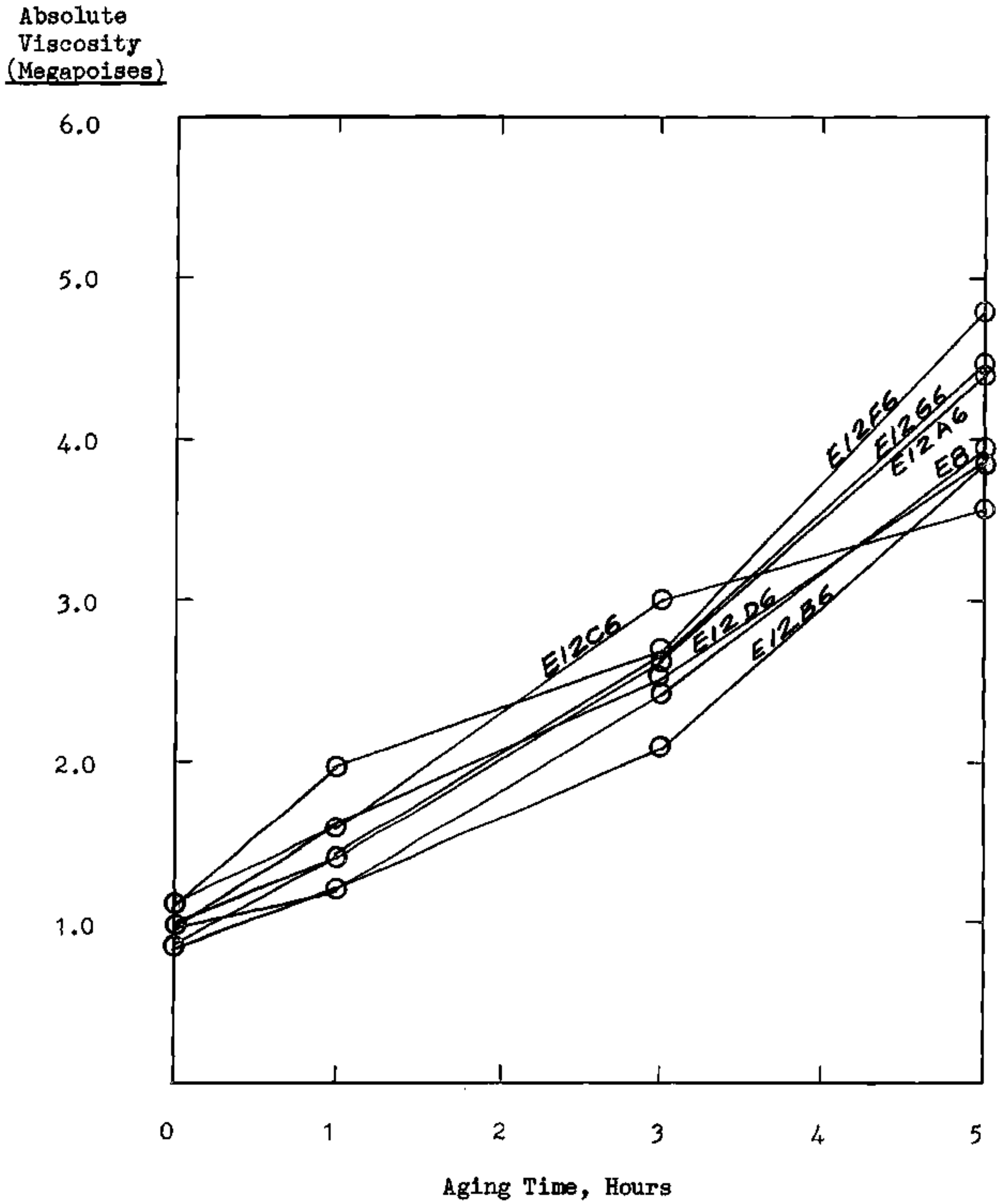

Figure 10. Relationship of Absolute Viscosity and Aging Time for the E12 Blends (American Bitumen and Asphalt, Bainbridge).

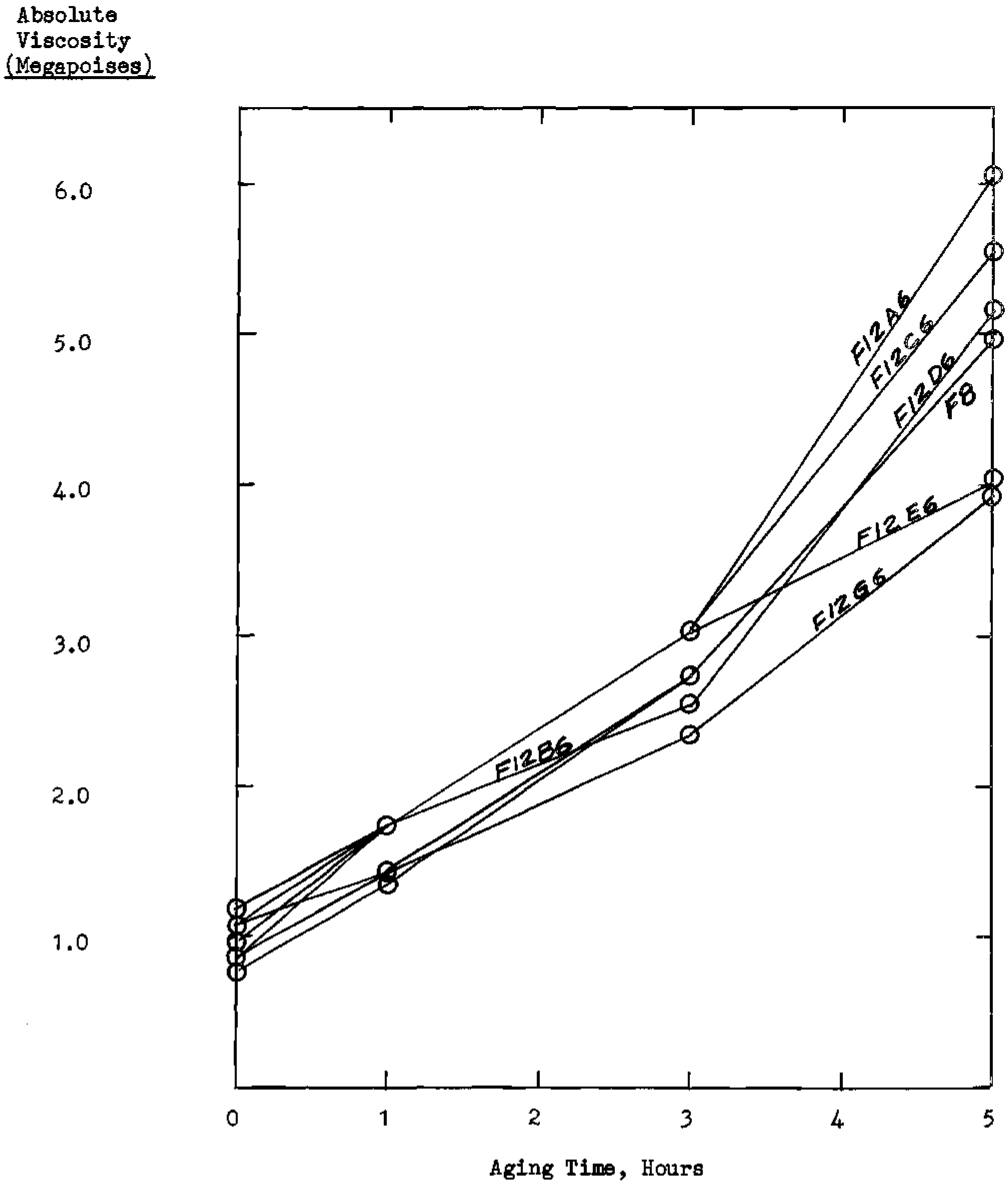

Figure 11. Relationship of Absolute Viscosity and Aging Time for the F12 Blends (American Bitumen and Asphalt, Savannah).

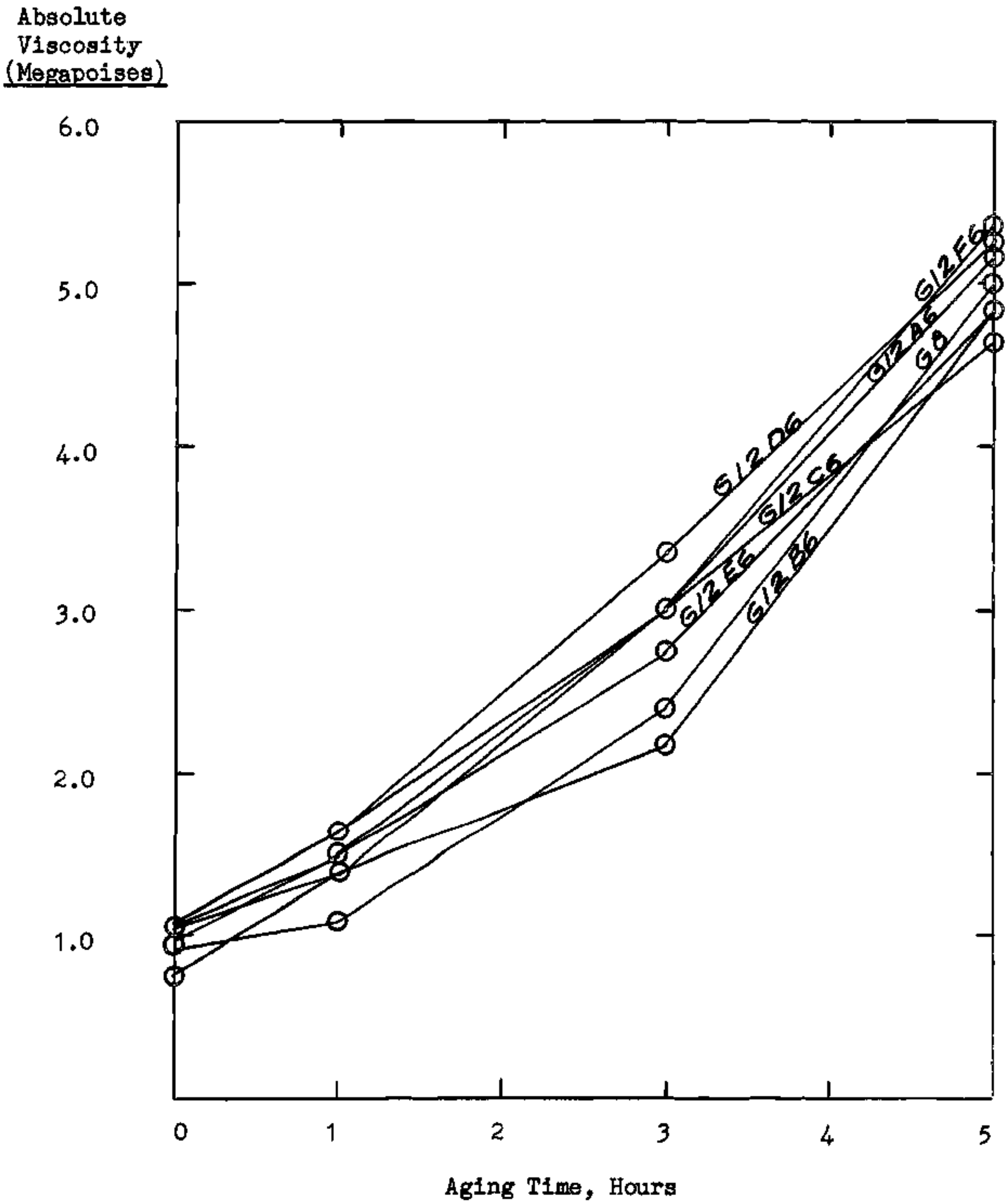

Figure 12. Relationship of Absolute Viscosity and Aging Time for the G12 Blends (Cracker Asphalt Corporation, Douglasville).

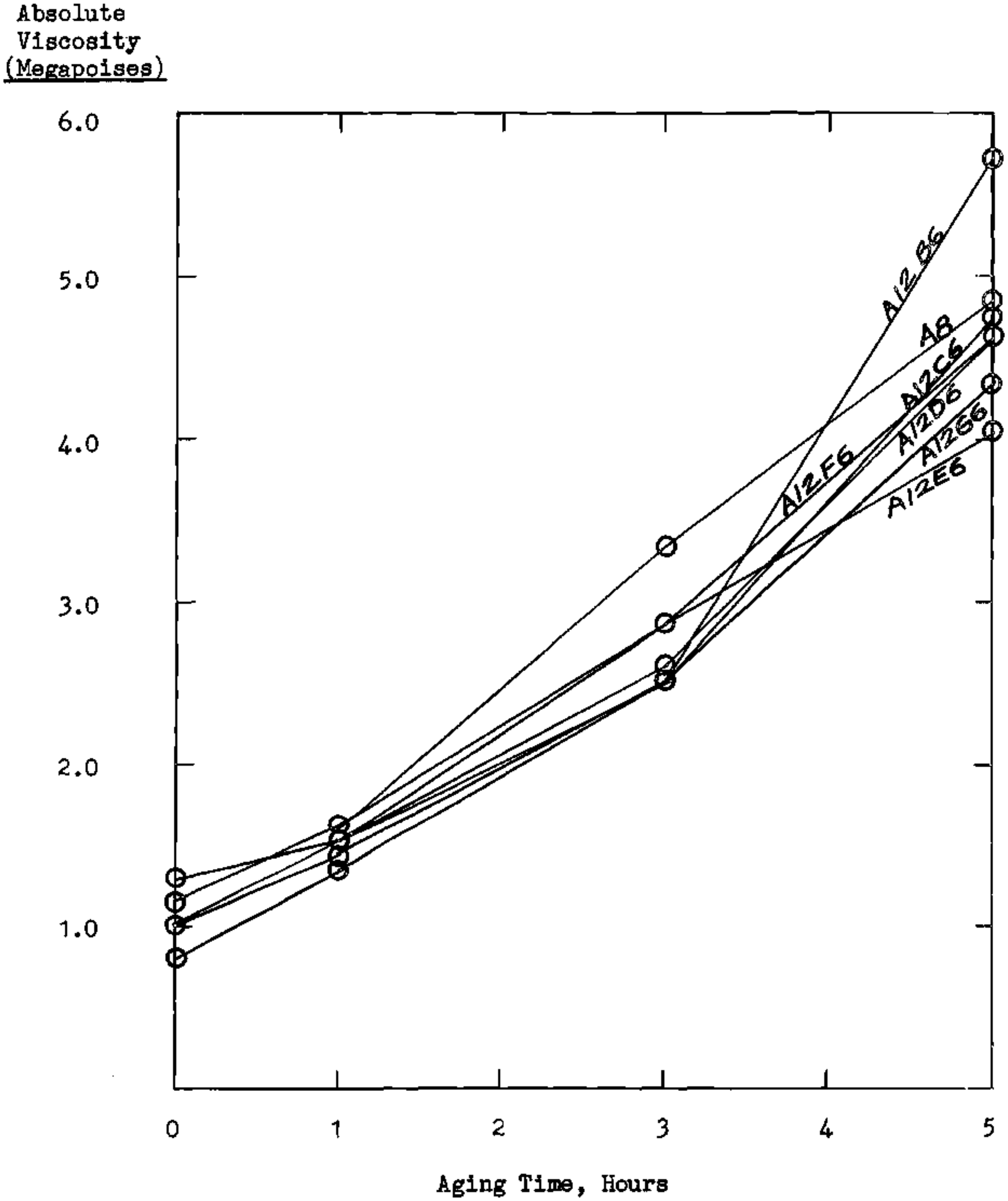

Figure 13. Relationship of Absolute Viscosity and Aging Time for the A12 Blends (Shell Oil Company, Atlanta).

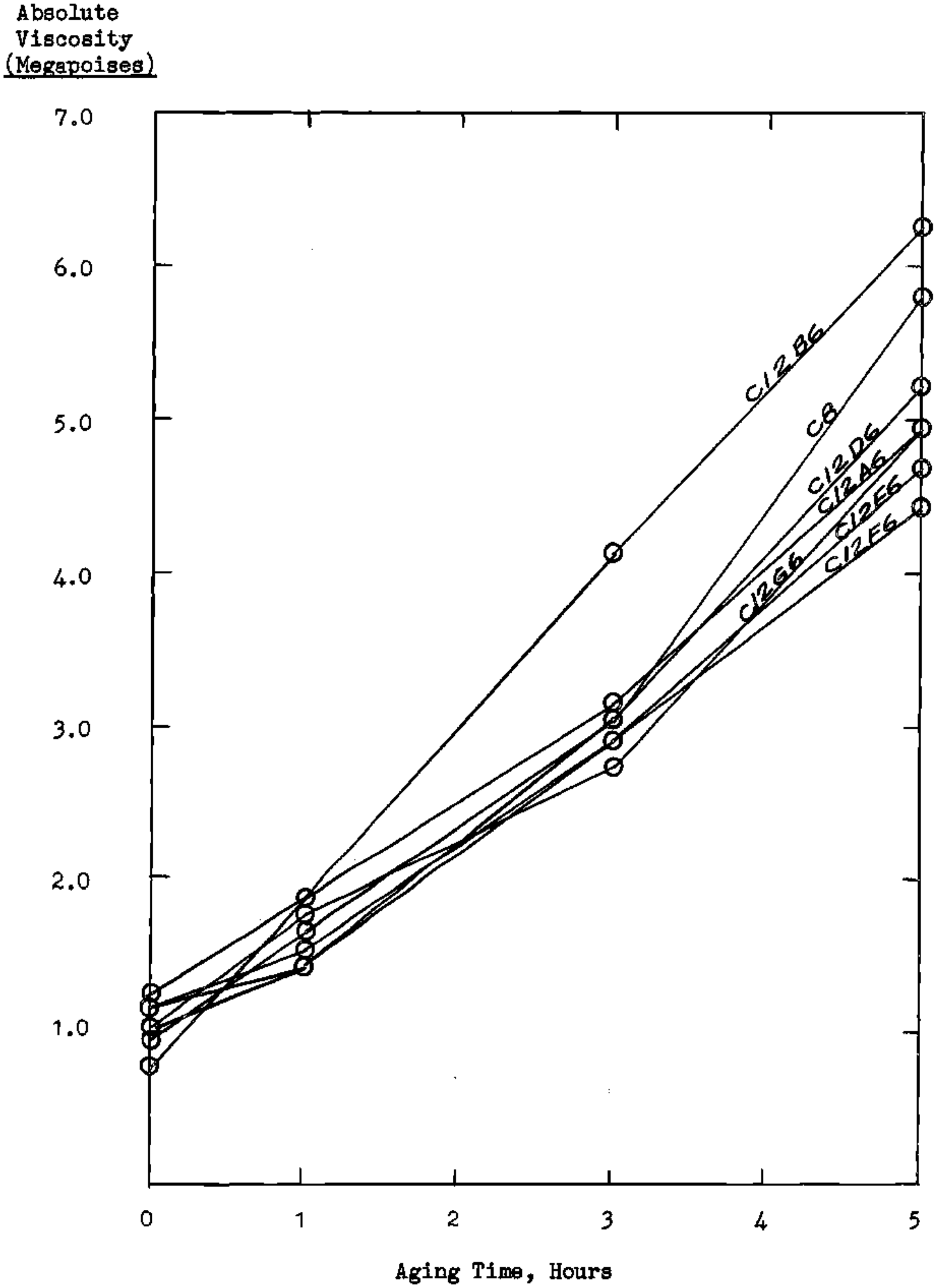

Figure 14. Relationship of Absolute Viscosity and Aging Time for the C12 Blends (American Oil Company, Savannah).

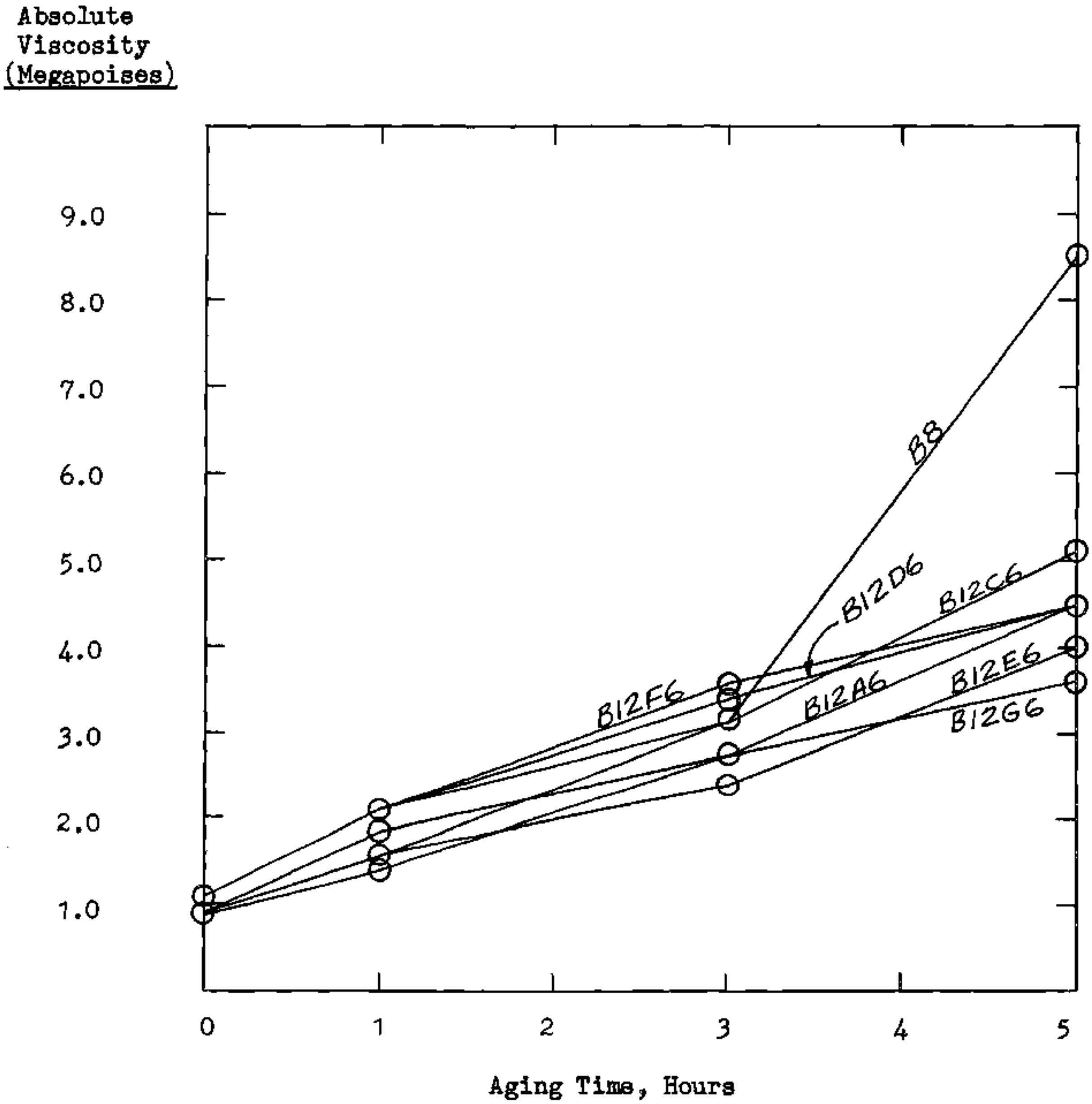

Figure 15. Relationship of Absolute Viscosity and Aging Time for the B12 Blends (Humble Oil Company, Charleston).

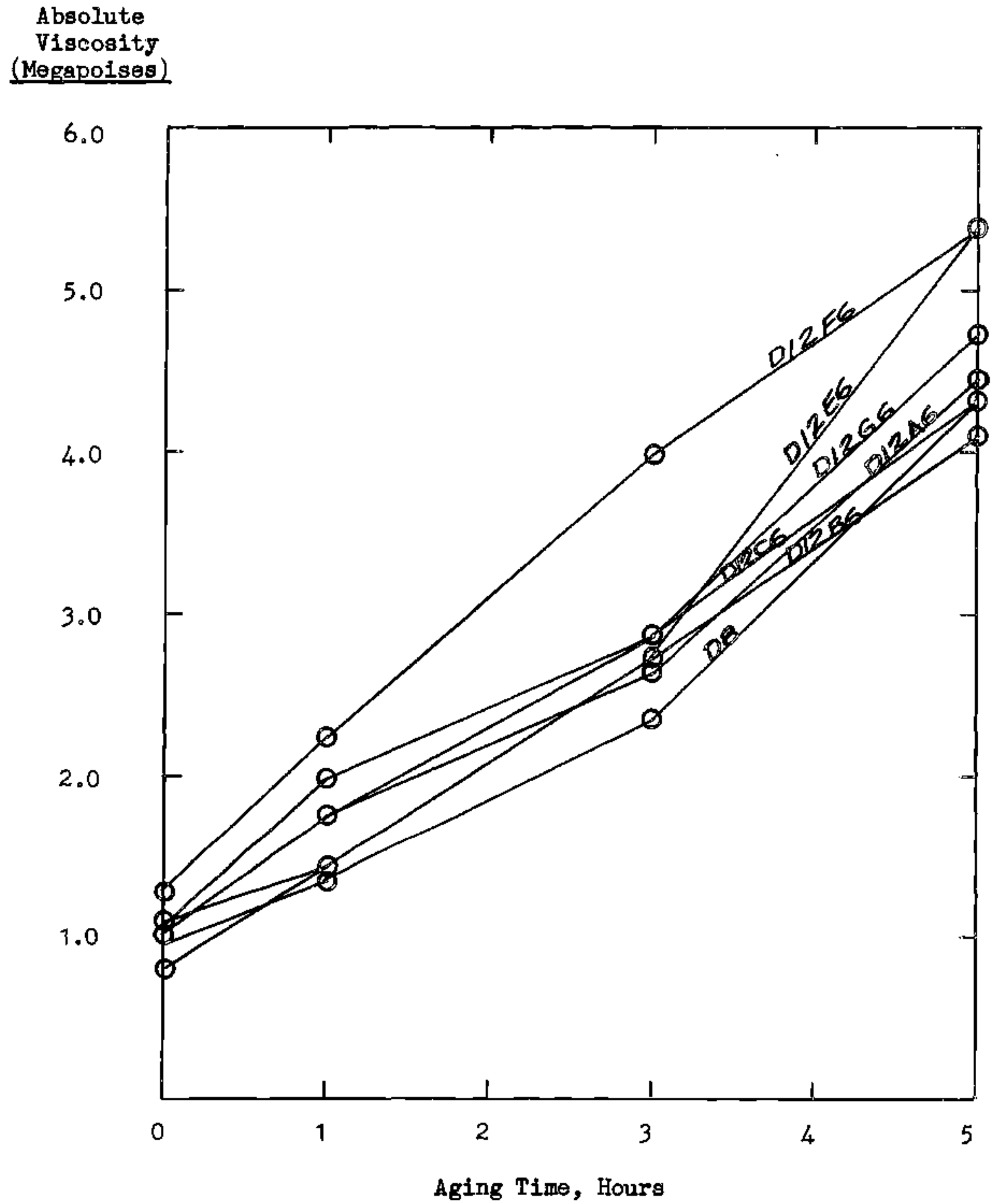

Figure 16. Relationship of Absolute Viscosity and Aging Time for the D12 Blends (Shell Oil Company, Savannah).

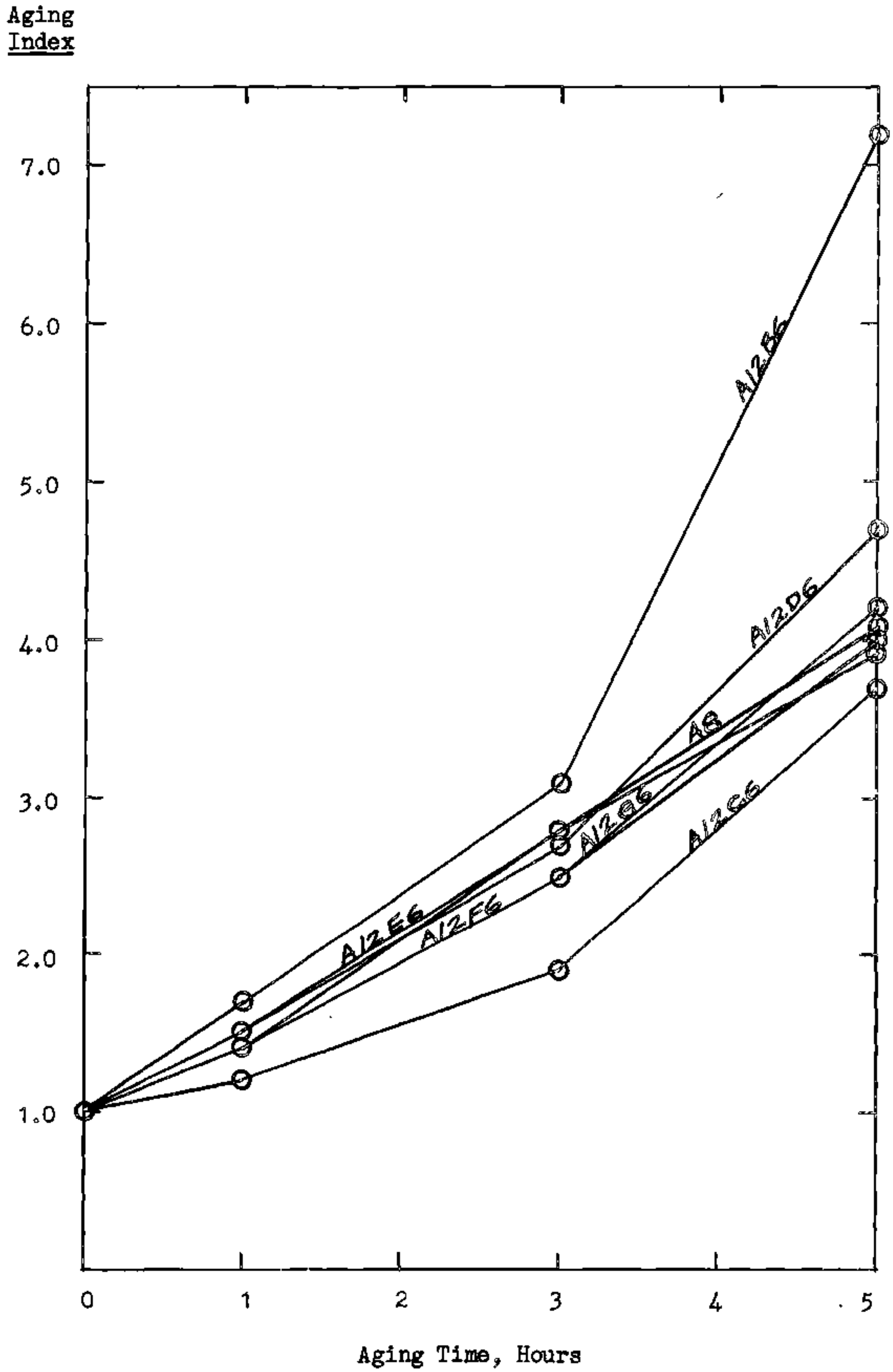

Figure 17. Relationship of Aging Index and Aging Time for the A12 Blends (Shell Oil Company, Atlanta).

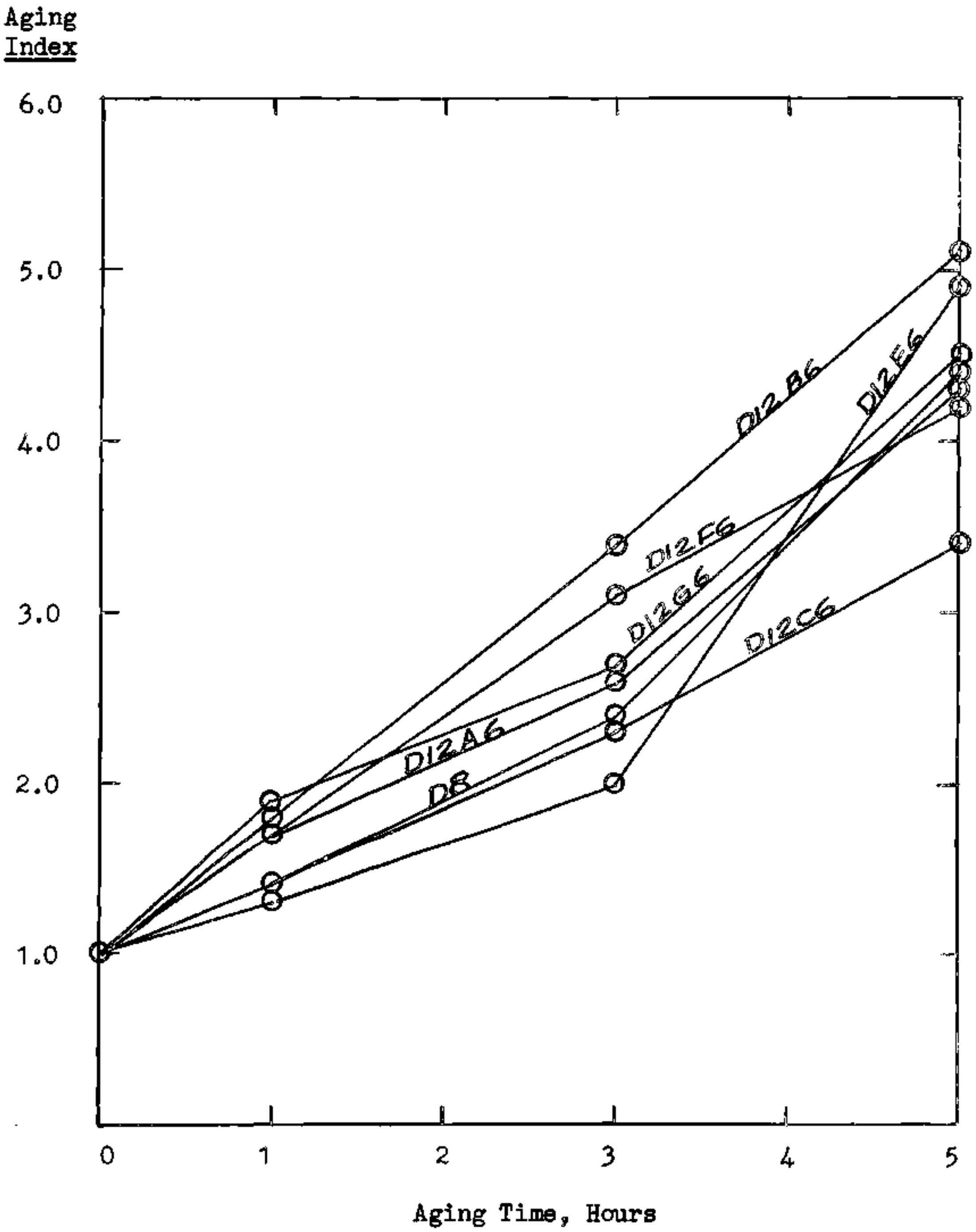

Figure 18. Relationship of Aging Index and Aging Time for the D12 Blends (Shell Oil Company, Savannah).

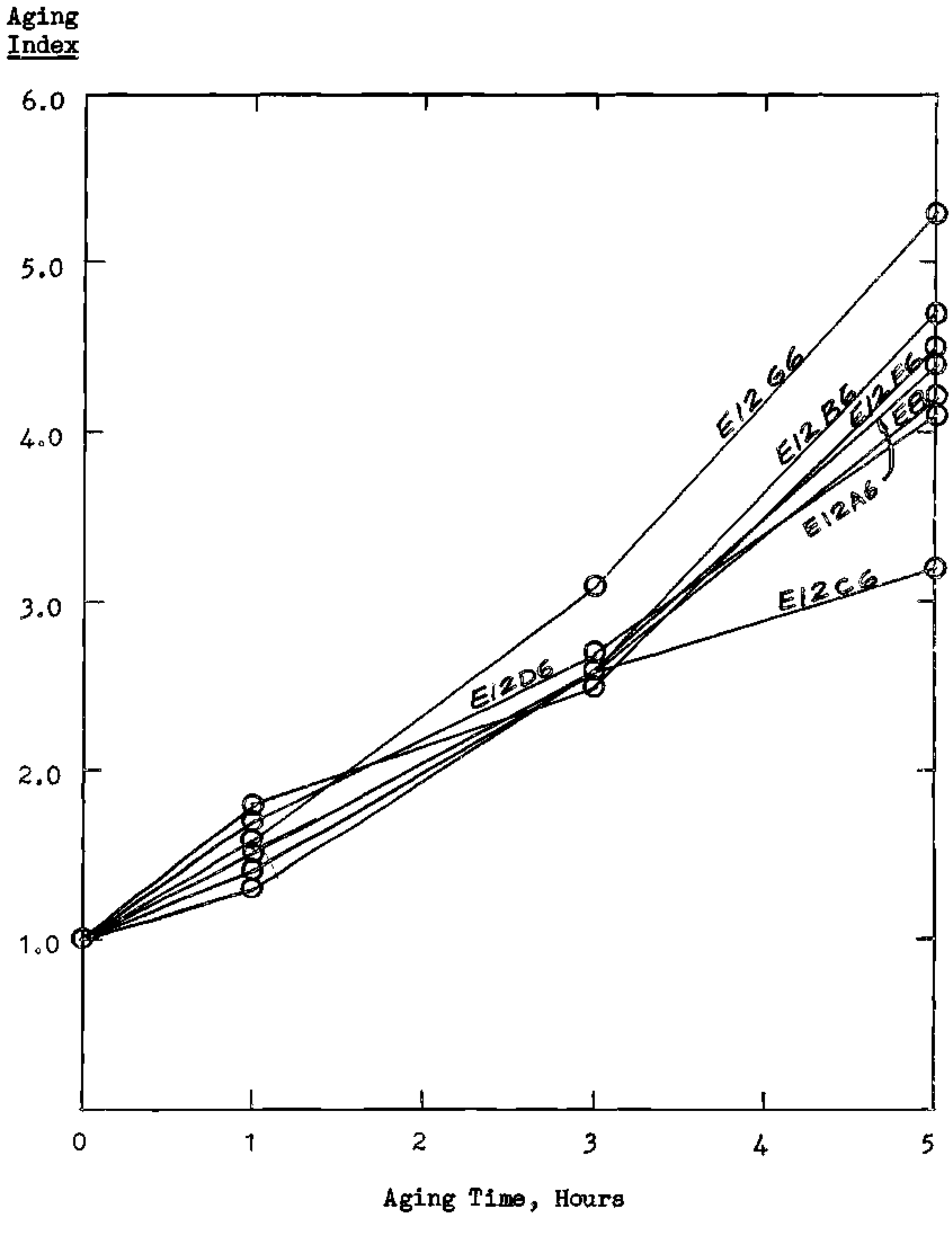

Figure 19. Relationship of Aging Index and Aging Time for the E12 Blends (American Bitumen and Asphalt, Bainbridge).

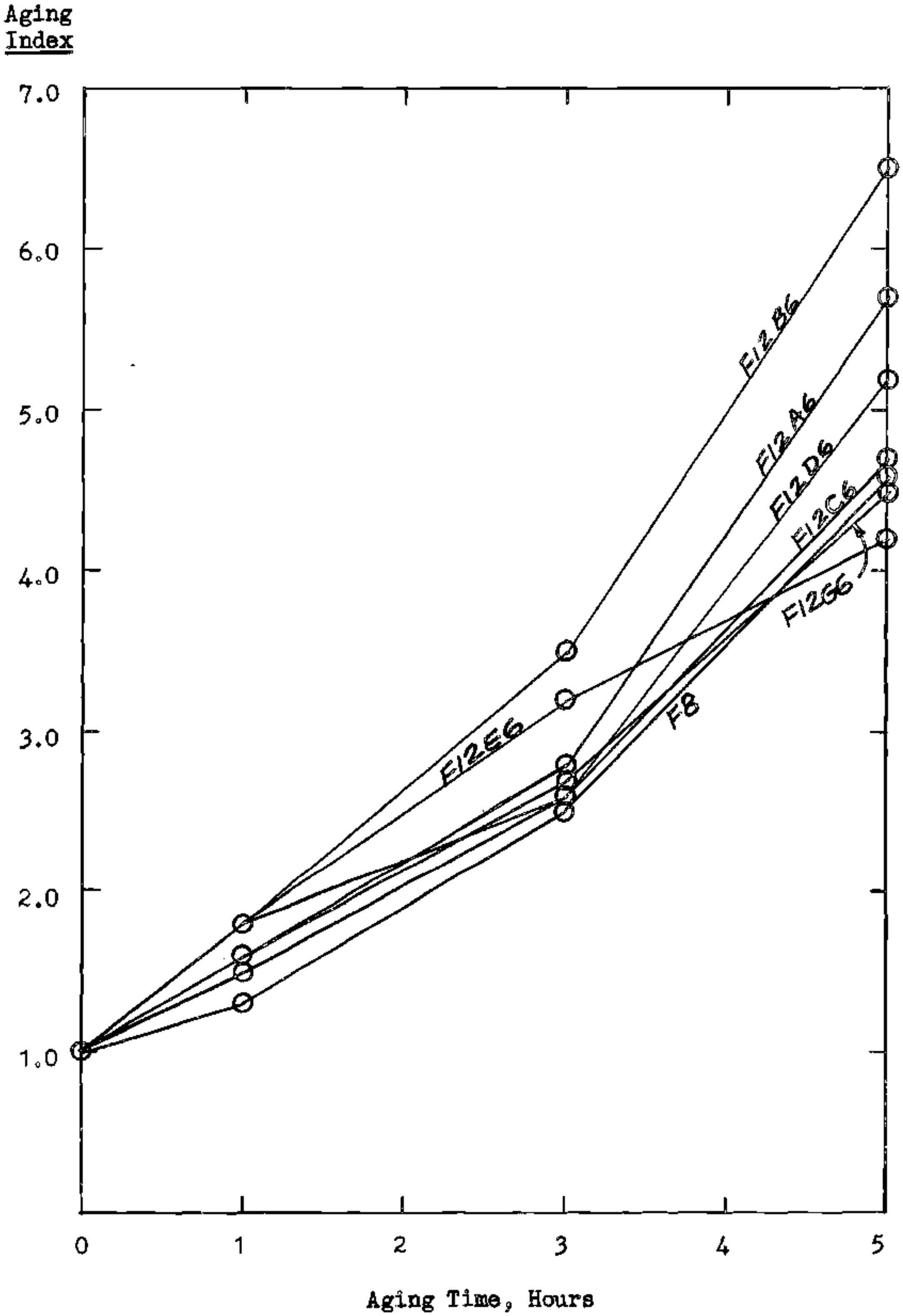

Figure 20. Relationship of Aging Index and Aging Time for the F12 Blends (American Bitumen and Asphalt, Savannah).

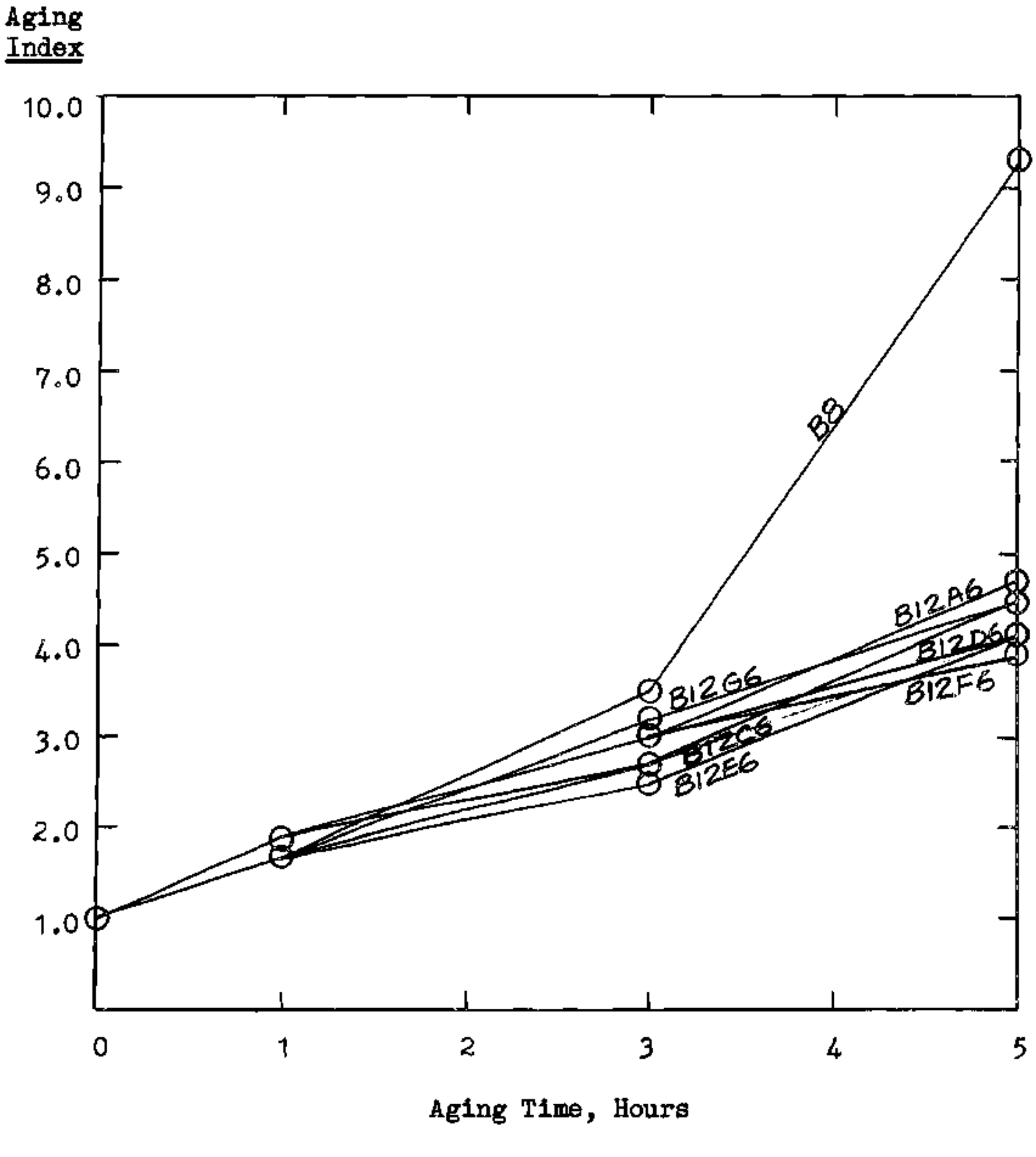

Figure 21. Relationship of Aging Index and Aging Time for the B12 Blends (Humble Oil Company, Charleston).

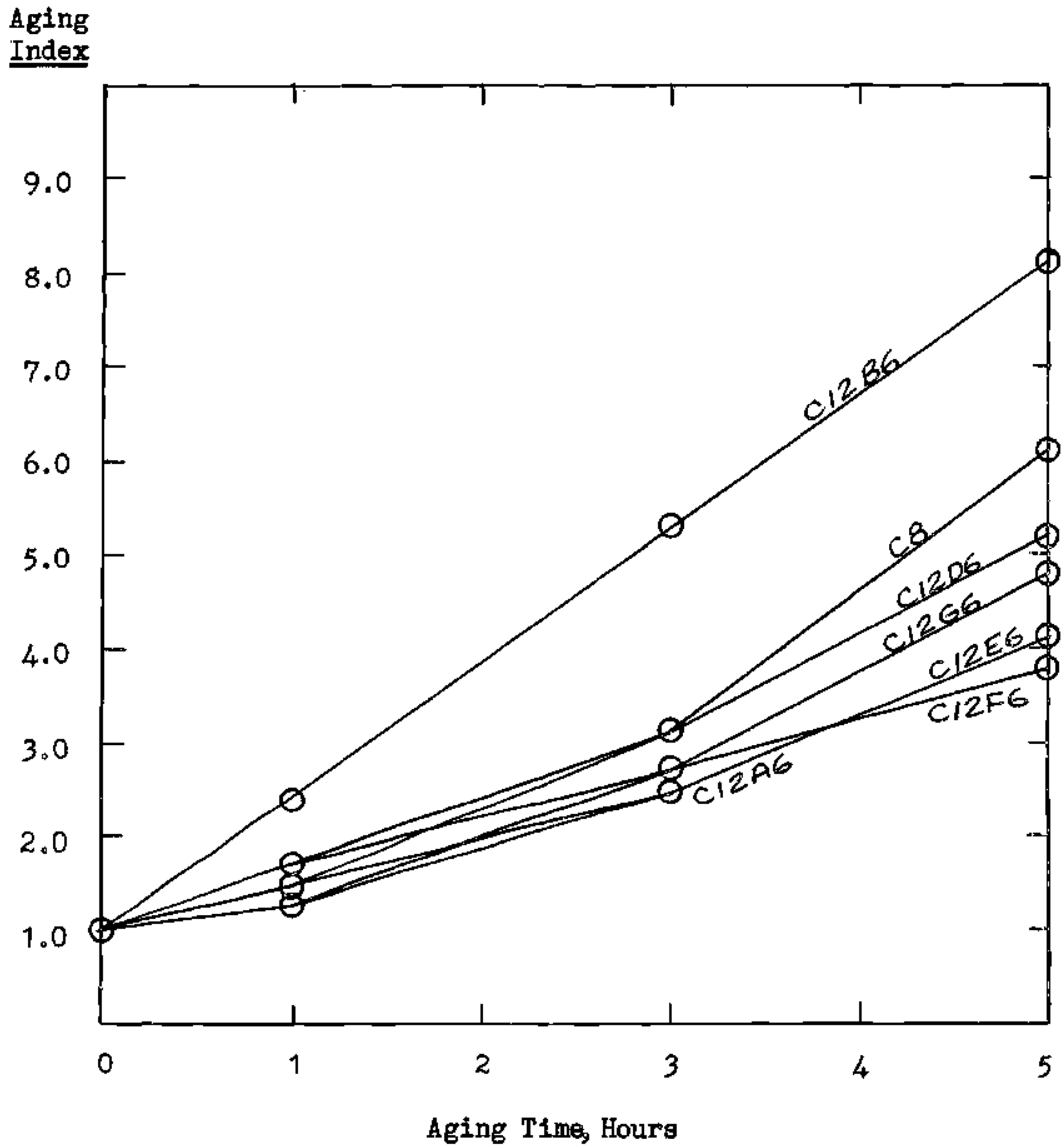

Figure 22. Relationship of Aging Index and Aging Time for the C12 Blends (American Oil Company, Savannah).

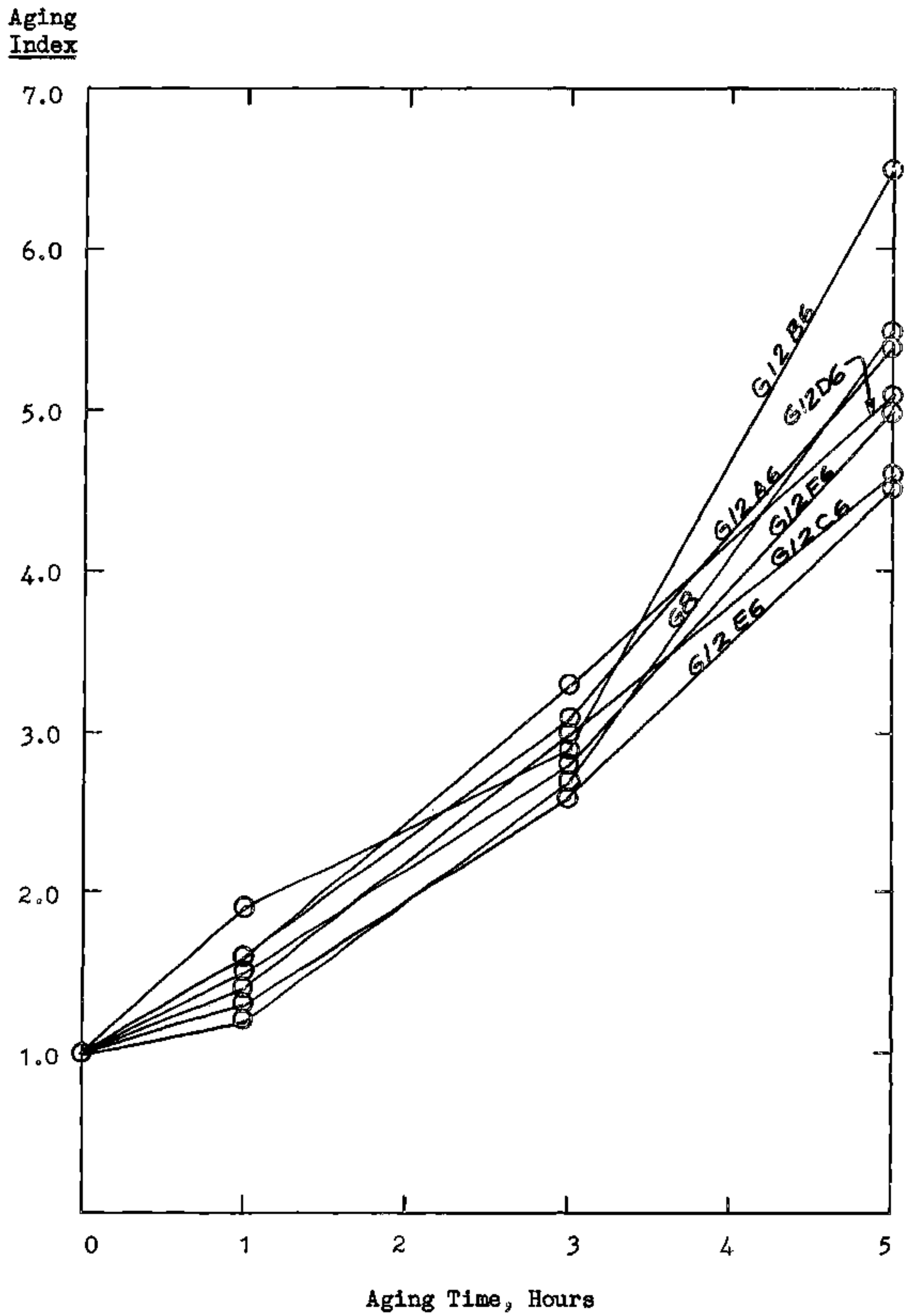

Figure 23. Relationship of Aging Index and Aging Time for the G12 Blends (Cracker Asphalt Corporation, Douglasville).

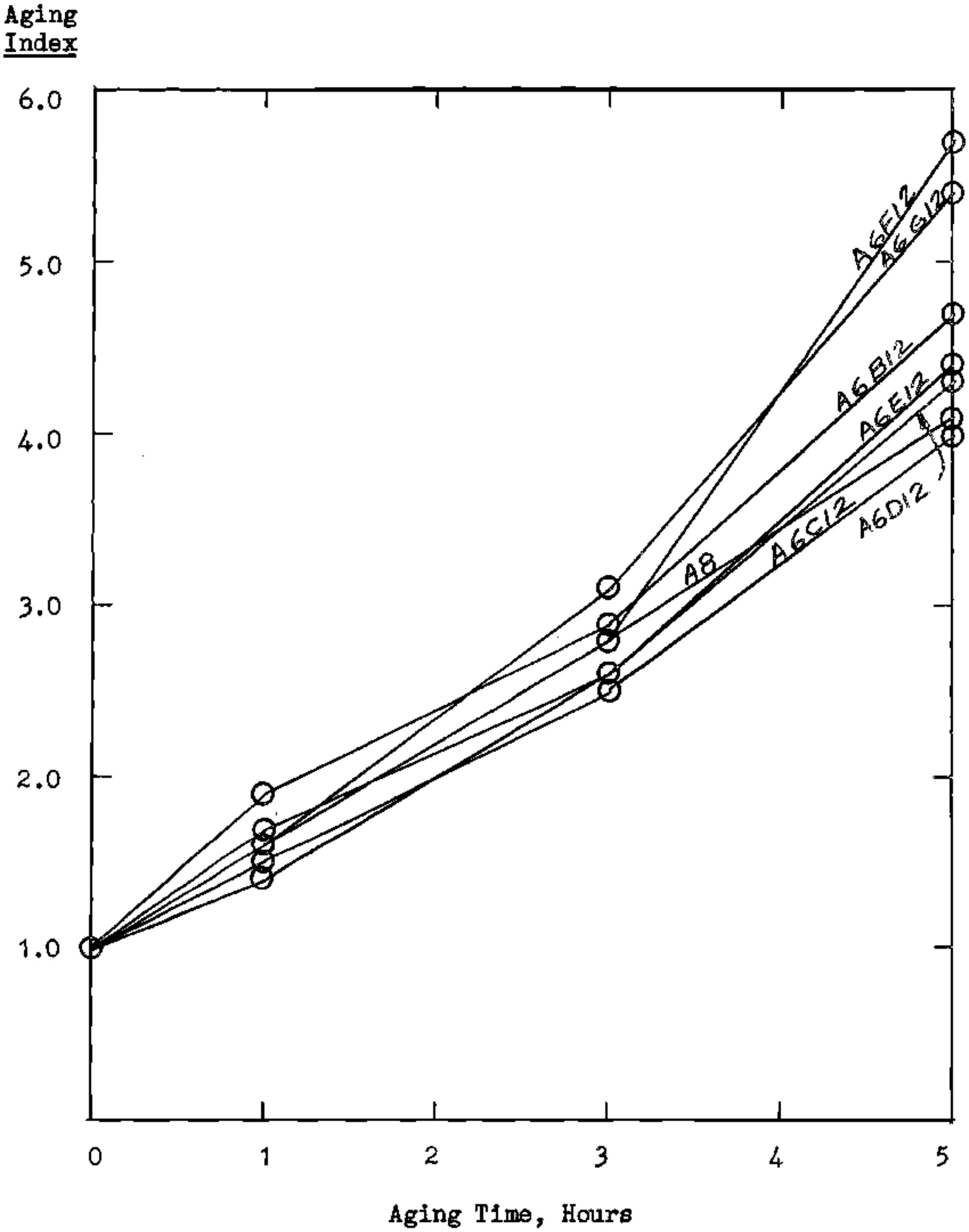

Figure 24. Relationship of Aging Index and Aging Time for the A6 Blends (Shell Oil Company, Atlanta).

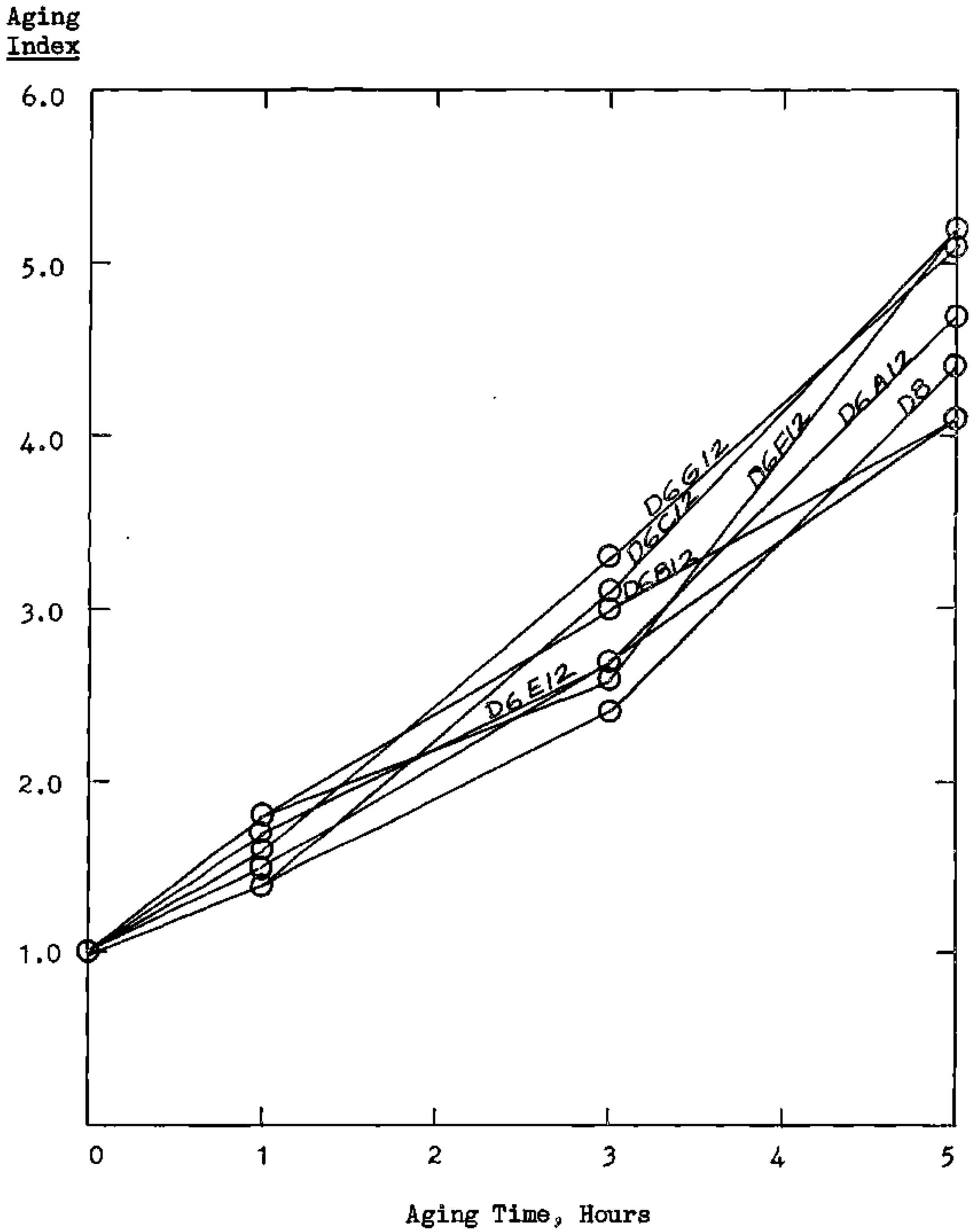

Figure 25. Relationship of Aging Index and Aging Time for the D6 Blends (Shell Oil Company, Savannah).

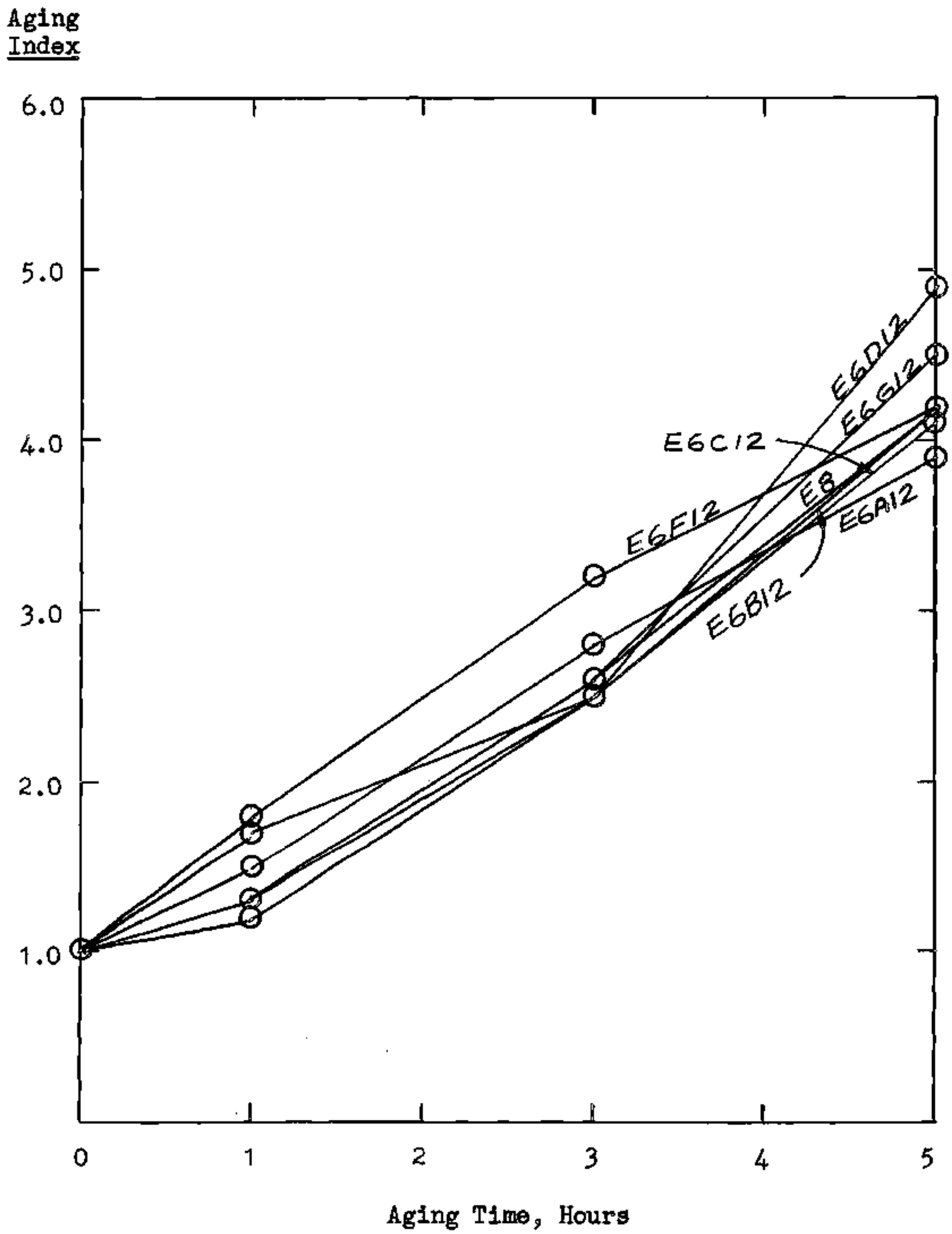

Figure 26. Relationship of Aging Index and Aging Time for the E6 Blends (American Bitumen and Asphalt, Bainbridge).

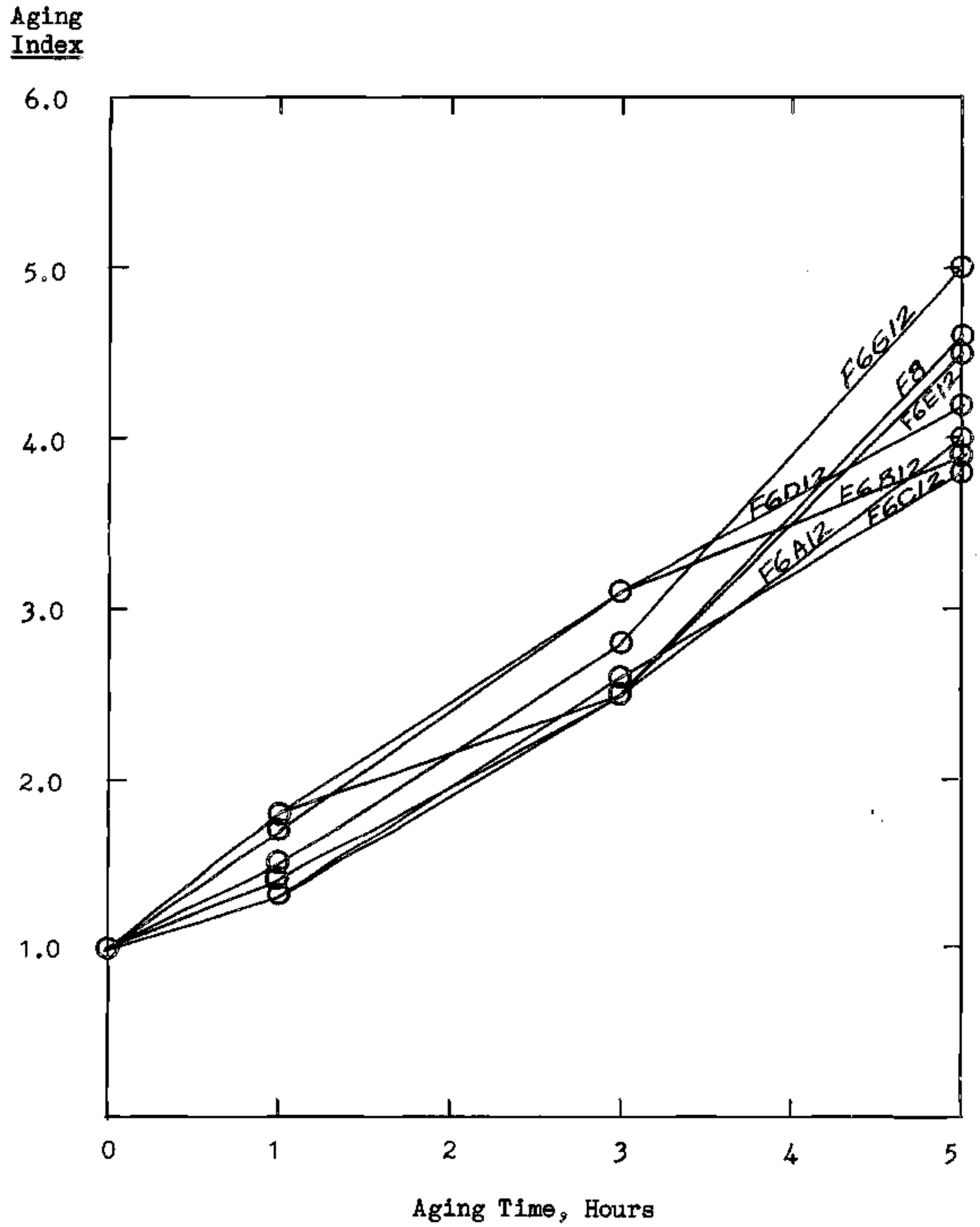

Figure 27. Relationship of Aging Index and Aging Time for the F6 Blends (American Bitumen and Asphalt, Savannah).

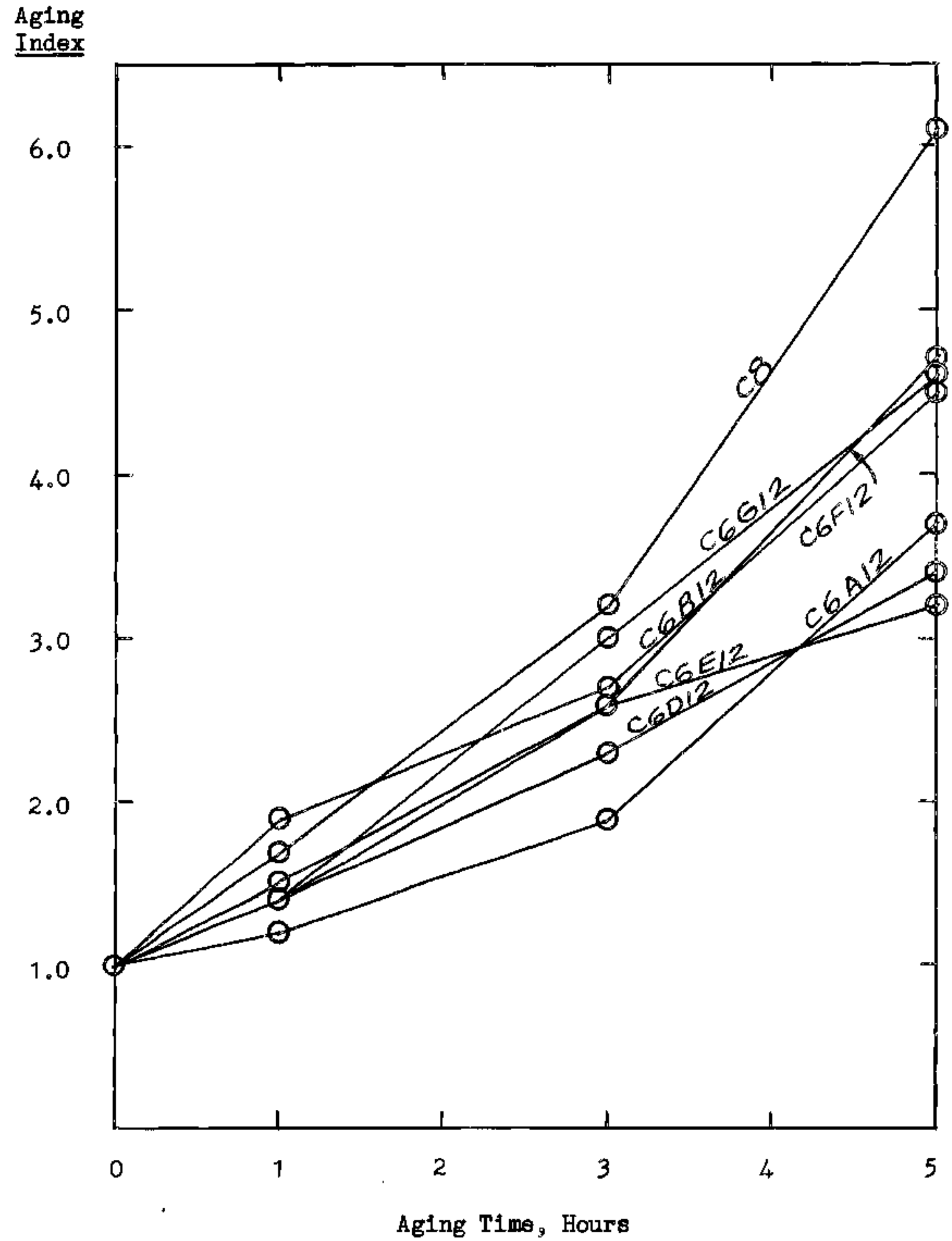

Figure 28. Relationship of Aging Index and Aging Time for the C6 Blends (American Oil Company, Savannah).

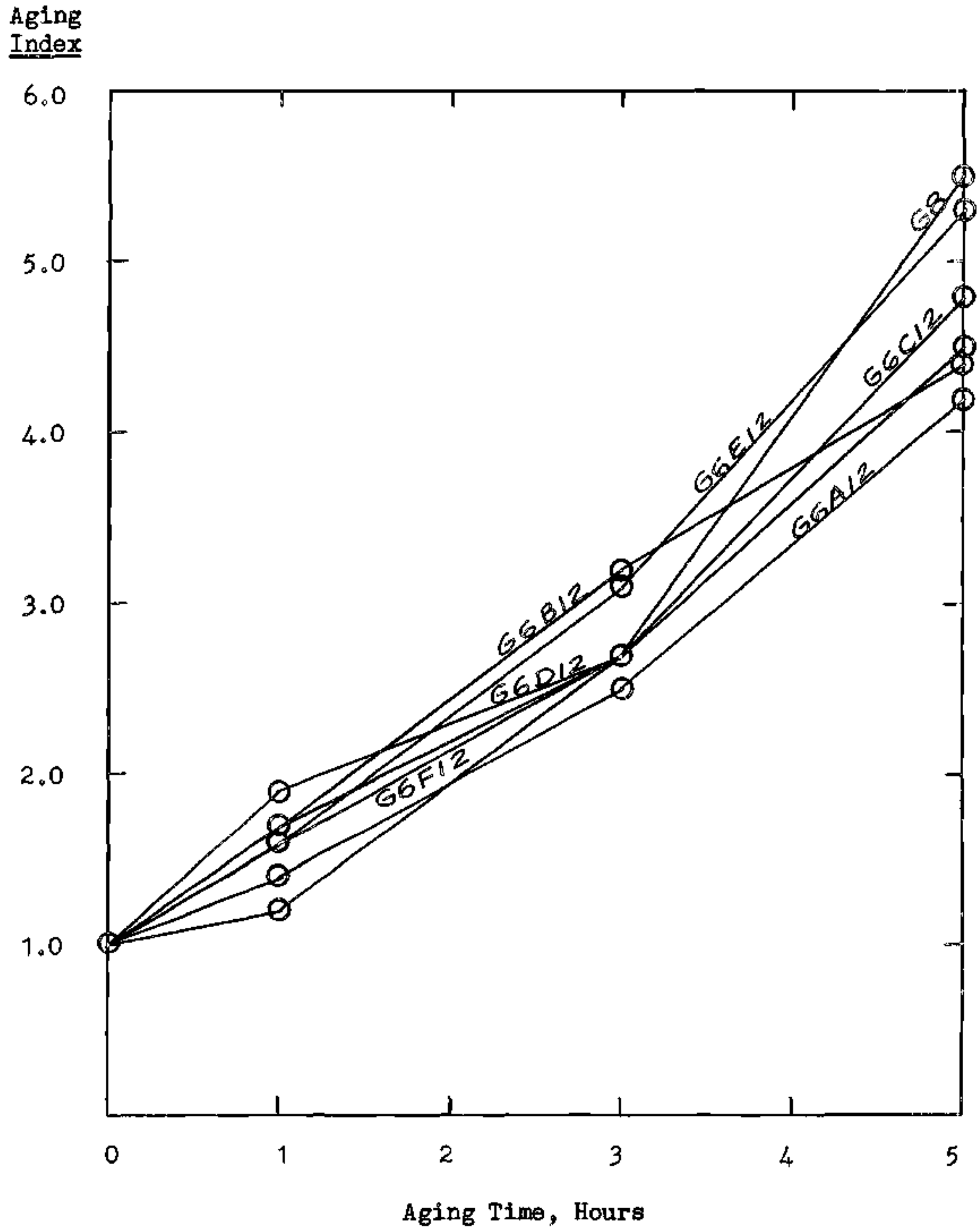

Figure 29. Relationship of Aging Index and Aging Time for the G6 Blends (Cracker Asphalt Corporation, Douglasville).

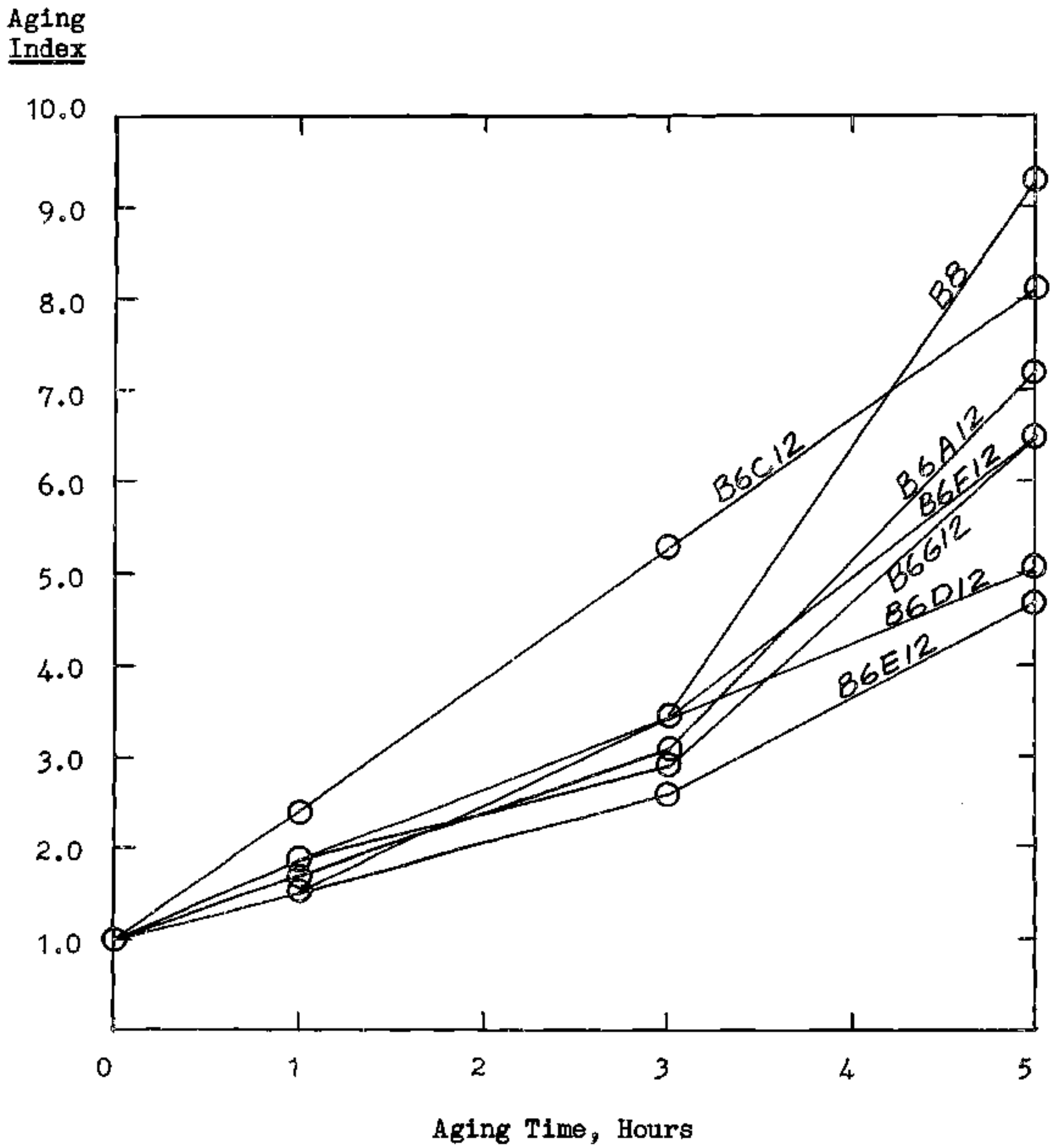

Figure 30. Relationship of Aging Index and Aging Time for the B6 Blends (Humble Oil Company, Charleston).

Table 7. Average Viscosity and Aging Index Results for the Original AC-8 Samples

Absolute Viscosity

Source	Unaged	One Hour	Three Hours	Five Hours
A	1.17	1.60	3.33	4.84
B	0.918	1.46	3.21	8.51
C	0.945	1.65	3.01	5.81
D	0.976	1.34	2.34	4.30
E	0.942	1.20	2.41	3.95
F	1.08	1.41	2.75	4.97
G	0.905	1.09	2.41	5.01

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
A	1.0	1.4	2.8	4.1
B	1.0	1.6	3.5	9.3
C	1.0	1.7	3.2	6.1
D	1.0	1.4	2.4	4.4
E	1.0	1.3	2.6	4.2
F	1.0	1.3	2.5	4.6
G	1.0	1.2	2.7	5.5

Table 8. Average Viscosity and Aging Index for the A6 and B6 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
A6B12	0.965	1.85	2.81	4.49
A6C12	1.24	1.88	3.15	4.96
A6D12	1.03	1.77	2.65	4.45
A6E12	1.01	1.42	2.62	4.40
A6F12	1.07	1.75	3.03	6.07
A6G12	0.965	1.50	3.01	5.17
B6A12	0.801	1.37	2.50	5.72
B6C12	0.777	**	4.13	6.26
B6D12	0.805	1.42	2.72	4.10
B6E12	0.811	1.21	3.10	3.82
B6F12	0.771	1.36	2.72	4.97
B6G12	0.749	1.42	2.18	4.88

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
A6B12	1.0	1.9	2.9	4.7
A6C12	1.0	1.5	2.5	4.0
A6D12	1.0	1.7	1.6	4.3
A6E12	1.0	1.4	2.6	4.4
A6F12	1.0	1.6	2.8	5.7
A6G12	1.0	1.6	3.1	5.4
B6A12	1.0	1.7	3.1	7.2
B6C12	1.0	**	5.3	8.1
B6D12	1.0	1.8	3.4	5.1
B6E12	1.0	1.5	2.6	4.7
B6F12	1.0	1.8	3.5	6.5
B6G12	1.0	1.9	2.9	6.5

* All viscosity values megapoises

** Sample destroyed

Table 9. Average Viscosity and Aging Index for the C6 and D6 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
C6A12	1.30	1.52	2.49	4.78
C6B12	1.15	2.18	3.13	5.14
C6D12	1.26	1.71	2.88	4.34
C6E12	1.13	1.59	3.00	3.58
C6F12	1.17	1.73	3.06	5.54
C6G12	1.01	1.38	3.01	4.64
D6A12	0.981	1.51	2.61	4.61
D6B12	1.11	2.03	3.37	4.49
D6C12	1.01	1.42	3.08	5.21
D6E12	0.940	1.61	2.50	3.88
D6F12	0.988	1.74	2.53	5.16
D6G12	1.03	1.60	3.35	5.24

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
C6A12	1.0	1.2	1.9	3.7
C6B12	1.0	1.9	2.7	4.5
C6D12	1.0	1.4	2.3	3.4
C6E12	1.0	1.4	2.6	3.2
C6F12	1.0	1.5	2.6	4.7
C6G12	1.0	1.4	3.0	4.6
D6A12	1.0	1.5	2.7	4.7
D6B12	1.0	1.8	3.0	4.1
D6C12	1.0	1.4	3.1	5.2
D6E12	1.0	1.7	2.7	4.1
D6F12	1.0	1.8	1.6	5.2
D6G12	1.0	1.6	3.3	5.1

* All viscosity values megapoises

Table 10. Average Viscosity and Aging Index for the E6 and F6 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
E6A12	1.03	1.50	2.88	4.04
E6B12	0.952	1.59	2.41	3.99
E6C12	1.15	1.43	2.88	4.69
E6D12	1.10	1.46	2.75	5.41
E6F12	0.957	1.72	3.02	4.05
E6G12	1.07	1.44	2.76	4.80
F6A12	1.15	1.64	2.90	4.65
F6B12	1.15	2.11	3.54	4.43
F6C12	1.16	1.52	2.96	4.42
F6D12	1.29	2.24	3.99	5.37
F6E12	1.07	1.97	2.69	4.80
F6G12	1.08	1.67	3.00	5.37

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
E6A12	1.0	1.5	2.8	3.9
E6B12	1.0	1.7	2.5	4.2
E6C12	1.0	1.2	2.5	4.1
E6D12	1.0	1.3	2.5	4.9
E6F12	1.0	1.8	3.2	4.2
E6G12	1.0	1.3	2.6	4.5
F6A12	1.0	1.4	2.5	4.0
F6B12	1.0	1.8	3.1	3.9
F6C12	1.0	1.3	2.6	3.8
F6D12	1.0	1.7	3.1	4.2
F6E12	1.0	1.8	2.5	4.5
F6G12	1.0	1.5	2.8	5.0

* All viscosity values megapoises

Table 11. Average Viscosity and Aging Index for the G6 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
G6A12	1.04	1.44	2.56	4.34
G6B12	0.829	1.42	2.67	3.63
G6C12	1.02	1.77	2.74	4.93
G6D12	1.06	1.99	2.88	4.72
G6E12	0.848	1.39	2.65	4.46
G6F12	0.874	1.43	2.34	3.93

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
G6A12	1.0	1.4	2.5	4.2
G6B12	1.0	1.7	3.2	4.4
G6C12	1.0	1.7	2.7	4.8
G6D12	1.0	1.9	2.7	4.5
G6E12	1.0	1.6	3.1	5.3
G6F12	1.0	1.6	1.7	4.5

* All viscosity values megapoises

Table 12. Average Viscosity and Aging Index for the A12 and B12 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
A12B6	0.801	1.37	2.50	5.72
A12C6	1.30	1.52	2.49	4.78
A12D6	0.982	1.51	2.61	4.61
A12E6	1.03	1.50	2.88	4.04
A12F6	1.15	1.64	2.90	4.65
A12G6	1.04	1.44	2.56	4.34
B12A6	0.965	1.85	2.81	4.49
B12C6	1.15	2.18	3.13	5.14
B12D6	1.11	2.03	3.37	4.49
B12E6	0.952	1.59	2.41	3.99
B12F6	1.15	2.11	3.54	4.43
B12G6	0.829	1.42	2.67	3.63

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
A12B6	1.0	1.7	3.1	7.2
A12C6	1.0	1.2	1.9	3.7
A12D6	1.0	1.5	2.7	4.7
A12E6	1.0	1.5	2.8	3.9
A12F6	1.0	1.4	2.5	4.0
A12G6	1.0	1.4	2.5	4.2
B12A6	1.0	1.9	2.9	4.7
B12C6	1.0	1.9	2.7	4.5
B12D6	1.0	1.8	3.0	4.1
B12E6	1.0	1.7	2.5	4.2
B12F6	1.0	1.8	3.1	3.9
B12G6	1.0	1.7	3.2	4.4

* All viscosity values megapoises

Table 13. Average Viscosity and Aging Index for the C12 and D12 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
C12A6	1.24	1.88	3.15	4.96
C12B6	0.777	**	4.13	6.26
C12D6	1.01	1.42	3.08	5.21
C12E6	1.15	1.43	2.88	4.69
C12F6	1.16	1.52	2.96	4.42
C12G6	1.02	1.77	2.74	4.93
D12A6	1.03	1.77	2.65	4.45
D12B6	0.805	1.42	2.72	4.10
D12C6	1.26	1.71	2.88	4.34
D12E6	1.10	1.46	2.75	5.41
D12F6	1.29	2.24	3.99	5.37
D12G6	1.06	1.99	2.88	4.72

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
C12A6	1.0	1.5	2.5	4.0
C12B6	1.0	**	5.3	8.1
C12D6	1.0	1.4	3.1	5.2
C12E6	1.0	1.2	2.5	4.1
C12F6	1.0	1.3	2.6	3.8
C12G6	1.0	1.7	2.7	4.8
D12A6	1.0	1.7	2.6	4.3
D12B6	1.0	1.8	3.4	5.1
D12C6	1.0	1.4	2.3	3.4
D12E6	1.0	1.3	2.5	4.9
D12F6	1.0	1.7	3.1	4.8
D12G6	1.0	1.9	2.7	4.5

* All viscosity values megapoises

** Samples destroyed

Table 14. Average Viscosity and Aging Index for the E12 and F12 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
E12A6	1.01	1.42	2.62	4.40
E12B6	0.811	1.21	2.10	3.82
E12C6	1.13	1.59	3.00	3.58
E12D6	0.940	1.61	2.50	3.88
E12F6	1.07	1.97	2.69	4.80
E12G6	0.848	1.39	2.65	4.46
F12A6	1.07	1.75	3.03	6.07
F12B6	0.771	1.36	2.72	4.97
F12C6	1.17	1.73	3.06	5.54
F12D6	0.988	1.74	2.53	5.26
F12E6	0.957	1.72	3.02	4.05
F12G6	0.874	1.43	2.34	3.93

Aging Index

Source	Unaged	One Hour	Three Hours	Five Hours
E12A6	1.0	1.4	2.6	4.4
E12B6	1.0	1.5	2.6	4.7
E12C6	1.0	1.4	2.6	3.2
E12D6	1.0	1.7	2.7	4.1
E12F6	1.0	1.8	2.5	4.5
E12G6	1.0	1.6	3.1	5.3
F12A6	1.0	1.6	2.8	5.7
F12B6	1.0	1.8	3.5	6.5
F12C6	1.0	1.5	2.6	4.7
F12D6	1.0	1.8	2.6	5.2
F12E6	1.0	1.8	3.2	4.2
F12G6	1.0	1.6	2.7	4.5

* All viscosity values megapoises

Table 15. Average Viscosity and Aging Index for the G12 Blends

Absolute Viscosity*

Source	Unaged	One Hour	Three Hours	Five Hours
G12A6	0.965	1.50	3.01	5.17
G12B6	0.749	1.42	2.18	4.88
G12C6	1.01	1.38	3.01	4.64
G12D6	1.03	1.60	3.35	5.24
G12E6	1.07	1.44	2.76	4.80
G12F6	1.08	1.67	3.00	5.37
		Aging Index		
G12A6	1.0	1.6	3.1	5.4
G12B6	1.0	1.9	2.9	6.5
G12C6	1.0	1.4	3.0	4.6
G12D6	1.0	1.6	3.3	5.1
G12E6	1.0	1.3	2.6	4.5
G12F6	1.0	1.5	2.8	5.0

* All viscosity values megapoises

Table 16. Weight Loss Results for the Original Source Samples

Source	Weight Loss	Per Cent Weight Loss
A	+ 0.2	+ 0.4
B	+ 0.3	+ 0.6
C	- 0.3	- 0.6
D	- 0.1	- 0.2
E	0	0
F	- 0.5	- 1.0
G	- 0.6	- 1.2

Weight Loss in Grams

Table 17. Weight Loss Results for the X6 Blends

Blend	Weight Loss	Per Cent Weight Loss	Blend	Weight Loss	Per Cent Weight Loss
A6B12	- 0.3	- 0.6	E6A12	0	0
A6C12	- 0.3	- 0.6	E6B12	- 0.2	- 0.4
A6D12	- 0.2	- 0.4	E6C12	+ 0.2	+ 0.4
A6E12	- 0.1	- 0.2	E6D12	- 0.1	- 0.2
A6F12	- 0.3	- 0.6	E6F12	0	0
A6G12	0	0	E6G12	- 0.1	- 0.2
B6A12	- 0.4	- 0.8	F6A12	- 0.1	- 0.2
B6C12	- 0.3	- 0.6	F6B12	- 0.1	- 0.2
B6D12	- 0.2	- 0.4	F6C12	- 0.3	- 0.6
B6E12	- 0.2	- 0.4	F6D12	- 0.1	- 0.2
B6F12	- 0.3	- 0.6	F6E12	- 0.2	- 0.4
B6G12	0	0	F6G12	- 0.3	- 0.6
C6A12	0	0	G6A12	- 0.4	- 0.8
C6B12	- 0.2	- 0.4	G6B12	- 0.2	- 0.4
C6D12	- 0.2	- 0.4	G6C12	- 0.3	- 0.6
C6E12	- 0.3	- 0.6	G6D12	- 0.3	- 0.6
C6F12	- 0.4	- 0.8	G6E12	- 0.2	- 0.4
C6G12	- 0.3	- 0.6	G6F12	- 0.7	- 1.4
D6A12	0	0			
D6B12	0	0			
D6C12	- 0.2	- 0.4			
D6E12	- 0.1	- 0.2			
D6F12	- 0.1	- 0.2			
D6G12	0	0			

Weight loss in grams

Table 18. Weight Loss Results for the X12 Blends

Blend	Weight Loss	Per Cent Weight Loss	Blend	Weight Loss	Per Cent Weight Loss
A12B6	- 0.4	- 0.8	E12A6	- 0.1	- 0.2
A12C6	0	0	E12B6	- 0.2	- 0.4
A12D6	0	0	E12C6	- 0.3	- 0.6
A12E6	0	0	E12D6	- 0.1	- 0.2
A12F6	- 0.1	- 0.2	E12F6	- 0.2	- 0.4
A12G6	- 0.4	- 0.8	E12G6	- 0.2	- 0.4
B12A6	- 0.3	- 0.6	F12A6	- 0.3	- 0.6
B12C6	- 0.2	- 0.4	F12B6	- 0.3	- 0.6
B12D6	0	0	F12C6	- 0.4	- 0.8
B12E6	- 0.2	- 0.4	F12D6	- 0.1	- 0.2
B12F6	- 0.1	- 0.2	F12E6	0	0
B12G6	- 0.2	- 0.4	F12G6	- 0.7	- 1.4
C12A6	- 0.3	- 0.6	G12A6	- 0.2	- 0.4
C12B6	- 0.3	- 0.6	G12B6	0	0
C12D6	- 0.2	- 0.4	G12C6	- 0.3	- 0.6
C12E6	+ 0.2	+ 0.4	G12D6	0	0
C12F6	- 0.3	- 0.6	G12E6	- 0.1	- 0.2
C12G6	- 0.3	- 0.6	G12F6	- 0.3	- 0.6
D12A6	- 0.2	- 0.4			
D12B6	- 0.2	- 0.4			
D12C6	- 0.2	- 0.4			
D12E6	- 0.1	- 0.2			
D12F6	- 0.1	- 0.2			
D12G6	- 0.3	- 0.6			

Weight loss in grams

Table 19. Theoretical Penetration Change for A6, B6, and C6 Blends

Blend	Unaged Viscosity	Five Hours Viscosity	Original Penetration	Final Penetration (From Formula)	Penetration Change
A6B12	0.965	4.49	86	49	37
A6C12	1.24	4.96	85	46	39
A6D12	1.03	4.45	87	49	38
A6E12	0.01	4.40	90	49	41
A6F12	1.07	6.07	93	41	52
A6G12	0.965	5.17	96	45	49
B6A12	0.801	5.72	92	42	50
B6C12	0.777	6.26	98	39	59
B6D12	0.805	4.10	95	52	43
B6E12	0.811	3.82	94	54	40
B6F12	0.771	4.97	97	46	51
B6G12	0.749	4.88	94	47	47
C6A12	1.30	4.78	89	47	42
C6B12	1.15	5.14	89	45	44
C6D12	1.26	4.34	88	50	38
C6E12	1.13	3.58	93	56	37
C6F12	1.17	5.54	89	43	46
C6G12	1.01	4.64	95	48	47

Viscosity values in megapoises

Table 20. Theoretical Penetration Change for D6, E6, and F6 Blends

Blend	Unaged Viscosity	Five Hours Viscosity	Original Penetration	Final Penetration (From Formula)	Penetration Change
D6A12	0.982	4.61	89	48	41
D6B12	1.11	4.49	86	49	37
D6C12	1.01	5.21	89	45	44
D6E12	0.940	3.88	85	53	32
D6F12	0.988	5.16	88	45	43
D6G12	1.03	5.24	85	45	40
E6A12	1.03	4.04	87	52	35
E6B12	0.952	3.99	93	52	41
E6C12	1.15	4.69	95	48	47
E6D12	1.10	5.41	91	44	47
E6F12	0.957	4.05	92	52	40
E6G12	1.07	4.80	95	47	48
F6A12	1.15	4.65	87	48	39
F6B12	1.15	4.43	87	49	38
F6C12	1.16	4.42	88	49	39
F6D12	1.29	5.37	85	44	41
F6E12	1.07	4.80	92	47	45
F6G12	1.08	5.37	88	44	44

Viscosity values in megapoises

Table 21. Theoretical Penetration Change for G6 Blends

Blend	Unaged Viscosity	Five Hours Viscosity	Original Penetration	Final Penetration (From Formula)	Penetration Change
G6A12	1.04	4.34	93	50	43
G6B12	0.829	3.63	97	55	42
G6C12	1.02	4.93	90	46	44
G6D12	1.06	4.72	93	47	46
G6E12	0.848	4.46	98	49	49
G6F12	0.874	3.93	95	53	42

Viscosity values in megapoises

Table 22. Theoretical Penetration Change for A12, B12, and C12 Blends

Blend	Unaged Viscosity	Five Hours Viscosity	Original Penetration	Final Penetration (From Formula)	Penetration Change
A12B6	0.801	5.72	92	42	50
A12C6	1.30	4.78	89	47	42
A12D6	0.982	4.61	89	48	41
A12E6	1.03	4.04	87	52	35
A12F6	1.15	4.65	87	48	39
A12G6	1.04	4.34	93	50	43
B12A6	0.965	4.49	86	49	37
B12C6	1.15	5.14	89	45	44
B12D6	1.11	4.49	86	49	37
B12E6	0.952	3.99	93	52	41
B12F6	1.15	4.43	87	49	38
B12G6	0.829	3.63	97	55	42
C12A6	1.24	4.96	85	46	39
C12B6	0.777	6.26	98	39	59
C12D6	1.01	5.21	89	45	44
C12E6	1.15	4.69	95	48	47
C12F6	1.16	4.42	88	49	39
C12G6	1.02	4.93	90	46	44

Viscosity values in megapoises

Table 23. Theoretical Penetration Change for D12, E12, and F12 Blends

Blend	Unaged Viscosity	Five Hours Viscosity	Original Penetration	Final Penetration (From Formula)	Penetration Change
D12A6	1.03	4.45	87	49	38
D12B6	0.805	4.10	95	52	43
D12C6	1.26	4.34	88	50	38
D12E6	1.10	5.41	91	44	47
D12F6	1.29	5.37	85	44	41
D12G6	1.06	4.72	93	47	46
E12A6	1.01	4.40	90	49	41
E12B6	0.811	3.82	94	54	40
E12C6	1.13	3.58	93	56	37
E12D6	0.940	3.88	85	53	32
E12F6	1.07	4.80	92	47	45
E12G6	0.848	4.46	98	49	49
F12A6	1.07	6.07	93	41	52
F12B6	0.771	4.97	97	46	51
F12C6	1.17	5.54	89	43	46
F12D6	0.988	5.16	88	45	43
F12E6	0.957	4.05	92	52	40
F12G6	0.874	3.93	95	53	42

Viscosity values in megapoises

Table 24. Theoretical Penetration Change for G12 Blends

Blend	Unaged Viscosity	Five Hours Viscosity	Original Penetration	Final Penetration (From Formula)	Penetration Change
G12A6	0.965	5.17	96	45	51
G12B6	0.749	4.88	94	47	47
G12C6	1.01	4.64	95	48	47
G12D6	1.03	4.24	85	45	40
G12E6	1.07	4.80	95	47	48
G12F6	1.08	5.37	88	44	44

Viscosity values in megapoises

DATA OBTAINED FROM MICROVISCOMETER TEST

Date 24 July 1965 Test Conducted by Hill

Sample Identification B6F12 Temperature 77 F

Plate No. 65 Aging Time of Sample 3 hours

Weight of Plates + Asphalt 16.0831 gms.

Weight of Plates 16.0505 gms.

Weight of Asphalt 0.0326 gms.

Specific Gravity of Asphalt 1.027 Area of Plate 6 cm^2.

$$\text{Film Thickness} = \frac{(\text{Weight of Asphalt})}{(\text{Asphalt Specific Gravity})(\text{Area of Plate})} \times 10^4$$

Film Thickness = 52.9 microns

Load, gms.	700	800	900
Shear Stress, dynes/cm^2.	114,331	130,664	146,997
Chart Movement, cms.	37	42	50
Shear Rate, sec^{-1}	3.88×10^{-2}	4.40×10^{-2}	5.25×10^{-2}
Viscosity, Poises	2.95×10^{6}	2.97×10^{6}	2.80×10^{6}

Absolute Viscosity at 0.05 $seconds^{-1}$, from graph, 2.83×10^6 poises

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